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Vertical Flight Noise Research and Development Plan

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16. Abstract

The FAA is confronting the challenge of addressing vertical flight noise issues through development of a five-year R&D program supported by the combined resources of its major noise certification office, the Office of Environment and Energy, and its vertical flight focal point, the Vertical Flight Program Office. A major step in that direction is publication of this document to enhance joint cooperation and execution.

This Vertical Flight Noise R&D Plan is designed as a program management tool to be used by FAA managers for project tasking and prioritization, and for resource allocation. Key issues and goals are identified, together with requirements (both near-term and long-range) that must be met to move toward those goals. Emphasis is on development of an integrated research plan that focuses on innovative and cost-effective solutions.

Four major aspects of vertical flight noise R&D are discussed:

- o technical,
- o operational,
- o regulatory, and
- o community acceptance.

In order to accomplish the goal of the overall program, all four areas must be addressed concurrently, with efforts in each area complementing and building on efforts in the other areas.

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1.0 INTRODUCTION

Vertical flight aircraft technology offers the potential to significantly enhance National Airspace System (NAS) capacity by the turn of the century. In recognition of this, the Federal Aviation Administration (FAA) is pursuing research and development (R&D) to identify modifications to the present infrastructure that will take advantage of this new and highly promising technology. Although vertical flight technology may offer increased public access to the NAS, it will also expose more of the public to noise and noise-related environmental issues, particularly with regard to vertiport operations in highly congested residential or urban environments. For this reason, vertical flight noise issues, if not adequately addressed and planned for in the near-term, have the potential to be a significant deterrent to successful integration of this technology into the existing NAS.

The FAA is confronting the challenge of addressing vertical flight noise issues through development of a 5-year R&D program supported by the combined resources of its major noise certification office, the Office of Environment and Energy (AEE), and its vertical flight focal point, the Vertical Flight Program Office (VFPO). A structured, integrated R&D process is planned to define the scope of the problem, as well as executing projects that will focus on innovative and cost-effective solutions. A major step in that direction is publication of this document in order to establish FAA consensus and enhance joint cooperation and execution.

1.1 BACKGROUND

The Department of Transportation has recognized the increasing importance of noise issues in planning the nation's transportation systems in their statement of 21st century goals (reference 1), one of which is to "protect the environment and the quality of life." More specifically, "Transportation cannot avoid affecting the environment, but a major goal of Federal transportation policy must be to minimize the negative side effects."

Several pieces of legislation have established the Federal government's authority to regulate noise. The FAA is the only agency of the U.S. government specifically directed by Congress to regulate aircraft for noise abatement purposes. This statutory authority is contained in the Federal Aviation Act of 1958.

FAA Order 1050.1E, "Policies and Procedures for Considering Environmental Impact," establishes FAA policies and procedures for preparation of Environmental Impact Statements (EIS) and Finding of No Significant Impact (FONSI), and for preparing and processing environmental assessments of FAA actions. This order implements the National Environmental Policy Act of 1969 (NEPA);

Department of Transportation (DOT) Order 5610C, "Procedures for Considering Environmental Impact;" and at least 25 other statutes, directives, and orders.

The primary Federal law pertaining to noise is the Noise Control Act of 1972. Predicated on the Federal power to regulate interstate and foreign commerce, this legislation authorizes the Environmental Protection Agency (EPA) to promulgate regulations concerning the maximum permissible noise characteristics of many products sold or otherwise moving in interstate commerce. The FAA, in turn, must respond formally to regulatory proposals made by the EPA. The Aviation Safety and Noise Abatement (ASNA) Act of 1979 required the FAA to establish by regulation a single system for determining the exposure of individuals to noise in the vicinity of airports. It also required the FAA to set up a standardized airport noise and land use compatibility program. Title 14 of the Code of Federal Regulations, Part 150 (14 CFR 150), Airport Noise Compatibility Planning, implements Title I of the ASNA Act.

Traditionally, the focus in vertical flight R&D has been on performance. For example, the Navy's V-22 program includes little emphasis on noise. However, now that vertical flight aircraft are being considered as a potential means of enhancing system capacity, noise issues have taken on higher priority. Many factors contribute to greater awareness of their importance. The FAA's stage 3 noise requirements for fixed-wing aircraft are being phased in, reducing the number of older, noisier aircraft. Current noise regulations do not adequately provide for advanced vertical flight (AVF) aircraft envisioned in the future. Stealth technology in the military arena now addresses the importance of quieter rotorcraft. Most importantly, the public is now much more concerned about the environmental impact of emerging transportation technology than in the past. In fact, community acceptance is arguably the major factor essential for successful vertical flight operations in the national transportation system.

Noise abatement technology transfer and applications are currently achievable. There is growing pressure from industry to adopt technology and procedures quickly. However, certification and regulatory actions, which are solely the Federal government's responsibility, require a relatively long lead time in terms of planning and coordination. AVF aircraft that are currently in the earliest stages of concept definition and development, and therefore not available yet for detailed acoustic testing, will likely require new or modified Federal noise regulations. The normal process is to develop certification requirements after a new type of aircraft is ready to be marketed by industry. However, if the required regulations could be developed concurrently with new aircraft, 2 to 3 years would be eliminated from the regulatory approval cycle. In addition, vertical flight aircraft manufacturers would have noise standards to design to,

resulting in more timely and efficient production of innovative, quiet aircraft.

1.2 PURPOSE

The purpose of this Vertical Flight Noise R&D Plan is to facilitate execution of the overall noise R&D program through disciplined project planning and management over a multi-year period. In keeping with the joint nature of this effort, the Plan also establishes the instrument for cooperation and coordination between AEE and the VFPO. It is designed as a program management tool to be used by FAA managers for project tasking and prioritization, and for resource allocation. Key issues and goals are identified, together with requirements that must be met to move toward those goals. Milestone schedules for accomplishing both near-term and long-range projects are included in section 7.0. Emphasis is on development of an integrated research plan with eventual transition to subsequent engineering and development.

The vertical flight noise R&D program will include participation by numerous organizations in government and industry, and academic institutions. This is in keeping with the "national" character of vertical flight technology implementation, as well as with the FAA's public/private partnership approach. To accurately reflect the broad spectrum of participation essential to this program, the Vertical Flight Noise R&D Plan was developed using inputs received from organizations representing those categories.

1.3 OBJECTIVES

The objectives of the Vertical Flight Noise R&D Plan include the following:

- to support the Rotorcraft Master Plan (RMP) and the Vertical Flight Program Plan by expanding on requirements and projects already identified in those plans in the area of vertical flight noise;
- to consolidate vertical flight noise R&D issues and requirements into a single document;
- to prioritize requirements in order to facilitate allocation of limited resources;
- to identify the status of noise R&D to date, including recent accomplishments;
- to formulate schedule and resource requirements for noise R&D efforts; and
- to stipulate roles and responsibilities for the various organizations involved in noise R&D.

1.4 PLAN ORGANIZATION

The intent of this document is to focus primarily on issues and constraints, and near-term and long-range requirements. Within each of those categories, four aspects of vertical flight noise R&D are discussed:

- o technical,
- o operational,
- o regulatory, and
- o community acceptance.

There are specific points to be made concerning each of these separate areas, yet it is essential to also view them as closely interrelated. In order to accomplish the goal of the overall program, all four areas must be addressed concurrently, with efforts in each area complementing and building on efforts in the other areas. It can be argued that the overriding challenge is community acceptance. On the other hand, if vertical flight aircraft are designed using innovative noise abatement technologies, if operational procedures are developed to minimize vertical flight noise in the terminal or vertiport environment, and if noise regulations are developed using metrics and noise levels that are acceptable to the public and the manufacturers, then community acceptance will be achieved. This plan attempts to define the challenge facing the FAA and other organizations involved in vertical flight noise R&D by identifying an integrated, systematic approach to resolving issues in the four areas listed above.

2.0 ROLES AND RESPONSIBILITIES

The vertical flight noise R&D program encompasses the efforts of multiple organizations, including government, industry, and academia. Joint cooperation and execution is required to successfully resolve issues and meet the requirements of the vertical flight community. A structured and integrated approach to program execution, including specific roles and responsibilities for each organization, further ensures that scarce resources are allocated in the most cost-effective manner.

2.1 FEDERAL AVIATION ADMINISTRATION

The roles and responsibilities for all organizations in FAA Headquarters are stipulated in FAA Order 1100.2C, "Organization, FAA Headquarters" (reference 2). That document was used as the source for the following descriptions, with the exception of the Southwest Regional Office.

2.1.1 Office of Environment and Energy (AEE)

Within the FAA, the office primarily responsible for noise certification and environmental issues is the Office of Environment and Energy. That office is responsible for:

- developing and recommending national aviation policies and strategies in environmental and energy matters;
- coordinating and managing FAA-wide actions and activities in support of national environmental quality and efficient energy conservation statutes, policies, goals, priorities, processes, and other requirements;
- formulating requirements for R&D programs to advance the state-of-the-art in environmental quality and efficient energy use and coordinating these requirements and resulting plans with other interested agencies;
- developing and coordinating aircraft noise and engine emission national standards for application as aircraft certification criteria and implementing engine emission national standards;
- acting as the focal point for supporting and encouraging community, state, local, and general public involvement and participation in the resolution of aviation environmental protection and energy conservation matters;
- coordinating with the Office of International Aviation on environmental matters concerning international civil aviation; and
- consulting and coordinating with the Office of the Chief Counsel in the interpretation of environmental legislation and orders.

More specifically, there are two separate divisions within AEE, each with defined responsibilities. The Technology Division has the following tasks within their area of responsibility:

- o formulation of technical programs to advance the state-of-the-art in aviation noise abatement ensuring the development of research and special studies in support of agency and statutory goals;
- o development of technical, engineering, economic, and analytical bases for implementing standards for aviation environmental protection, including development of state-of-the-art aircraft noise evaluations;
- o development of technical methods for the measurement, correction, and analysis of aircraft noise from individual aircraft and from cumulative impacts in or around airports;
- o evaluation of the use of aircraft operating techniques as a means for alleviating adverse noise or emissions impacts; and
- o maintenance of technical liaison with industry, scientific groups, the National Aeronautics and Space Administration (NASA), EPA, and other agencies to ensure responsiveness to and compatibility with other ongoing aircraft noise research efforts.

The Policy and Regulatory Division is responsible for the following tasks:

- o development of environmental policies, goals, and priorities;
- o development and promulgation of regulations establishing national aircraft noise standards; and
- o acting as focal point in evaluations of airport-proprietor-use restrictions and land-use planning for environmental purposes.

2.1.2 Vertical Flight Program Office (VFPO)

The other office in the FAA playing a major role in vertical flight noise R&D is the Vertical Flight Program Office. This plan is the instrument that establishes coordination and cooperation between AEE and the VFPO. The VFPO identifies, initiates, and coordinates actions to facilitate the introduction of vertical flight aircraft into the NAS and to contribute to development of comprehensive, national FAA vertical flight policy, plans, and programs. Specific responsibilities include:

- o serving as the agency's focal point to integrate the capabilities of vertical flight aircraft with other system components to enhance a safe and effective air transportation system;

- coordinating, participating, and establishing working relationships with the Department of Defense (DOD), the Department of Commerce, NASA, industry, and other government agencies via memorandums of agreement or understanding, as required, to allow access to information and plans which have a bearing on the use of vertical flight aircraft in a civilian environment;
- developing requirements for research, development, test, and evaluation projects, encouraging the efforts of private industry to enhance vertical flight-related development, and ensuring coordinated resolution of technology research, development, and economic issues related to vertical flight introduction;
- developing a Vertical Flight Program Plan which documents the strategy and tactics of making vertical flight technology a viable component of the civil aviation environment, and facilitating integration of this plan into the FAA Rotorcraft Master Plan; and
- working with the technical program offices that:
  - recommend additions, deletions, or changes in agency vertical flight program goals and objectives, and
  - prepare and submit for review those program and project plans proposed for accomplishment in support of vertical flight goals and objectives.

2.1.3 Rotorcraft Directorate

The Rotorcraft Directorate, Aircraft Certification Service (ASW-100) located in the Southwest Regional Office acts as the lead field organization for rotorcraft noise certification and, as such, is responsible for the following:

- review and approval of noise certification test plans for vertical flight aircraft prior to testing;
- providing an FAA witness for actual field tests if not provided by the applicant's local certification office;
- review of certification test data for vertical flight aircraft to ensure compliance with approved criteria and final sign-off on noise certification after the test is conducted; and
- providing technical assistance to AEE as necessary to support development or modification of noise regulations affecting vertical flight aircraft.

2.1.4 Related Headquarters Organizations

In addition to the offices with primary responsibility for the vertical flight noise R&D program, there are other offices within FAA Headquarters with some level of involvement in the program.

2.1.4.1 Office of International Aviation (AIA)

The Office of International Aviation serves as the point of contact for the U.S. aviation industry with respect to agency policies and programs affecting international civil aviation, including the International Civil Aviation Organization (ICAO). Their responsibilities include the following:

- formulating and coordinating agency policies governing ICAO matters and developing criteria for determining FAA participation in ICAO and other international meetings;
- negotiating agreements and arrangements concerning the international aviation activities of the agency; and
- serving as the FAA focal point in relations with international organizations affecting aviation, providing or arranging for agency participation in international meetings of such organizations, and developing and coordinating agency views on positions for such meetings through the Interagency Group on International Aviation.

2.1.4.2 Office of Public Affairs (APA)

The Office of Public Affairs is the principal liaison with consumer groups, local communities, industry, aviation organizations, and citizen aviation groups to foster and promote aviation and public availability of information. Their responsibilities include the following:

- acting as principal public spokesperson for the FAA to external sources on matters of public affairs;
- planning community relations programs to foster understanding and cooperation between the FAA, various communities, and local governments;
- developing and maintaining a national network of contacts in state and local governments, the aviation industry, and the education community to help promote aviation education goals and objectives; and
- administering the aviation education program by evaluating and developing aviation education materials for use by teachers and students and by those involved in developing aviation-related curricula in the nations's school systems, serving as a national clearinghouse of resources for this aviation education material, and managing a computerized national aviation education information resource system for public and private use.

2.1.4.3 Office of the Chief Counsel (AGC)

The Office of the Chief Counsel provides legal counsel with respect to the drafting, form, and legality of all substantive, procedural, and interpretative rules, regulations, orders, exemptions, airspace actions, and obstruction evaluation determinations which the FAA adopts or issues. In issuing legal interpretations, AGC maintains close working relationships with the offices and services responsible for the substance of the rules. In the case of regulatory actions governing aircraft noise, that office is AEE. The responsibilities of AGC include:

- providing legal guidance and counsel to the office or service having substantive rulemaking responsibilities in the preparation of environmental regulatory action or responsibility for preparation and drafting of directives to be used by FAA personnel in considering and analyzing airport environmental questions and issues to assure achievement of the intended result and compliance with applicable airport and environmental laws, guidelines, regulations, policies, and procedures;
- providing FAA representation with respect to legal problems arising out of international aviation, including consultation and liaison as required with legal offices of other agencies of the government, and preparation of a suggested U.S. position for international law meetings of ICAO and for diplomatic conferences involving problems of international law; and
- reviewing, preparing legal analysis, and counselling on the relationship between environmental statutes, guidelines, and rules, and various FAA ongoing programs, actions, or special projects.

2.1.4.4 Office of Airport Planning and Programming (APP)

The Office of Airport Planning and Programming administers the program for environmental review and documentation of airport projects, the airport noise compatibility planning program under 14 CFR 150, and other airport program activities relating to environmental issues. However, APP adheres to policy guidance developed by AEE and approved by the FAA Administrator when processing and coordinating environmental impact statements, noise exposure maps, and noise compatibility programs, or when implementing legislative environmental provisions contained in the Airport and Airway Improvement Act, the Aviation Safety and Noise Abatement Act, section 102(2)(C) of the National Environmental Policy Act of 1969, and section 4(f) of the Department of Transportation Act. APP's responsibilities in the area of noise R&D include the following:

- managing FAA Headquarters processing of environmental actions for airport projects and other airport program activities relating to the preservation of environmental quality, including review for adequacy and conformance with requirements and recommendations for approval or disapproval;
- providing program guidance and serving as contact point for the regions during review of noise exposure maps and noise compatibility programs submitted under 14 CFR 150, and recommending noise compatibility program approval or disapproval; and
- maintaining liaison with and representing the office to other elements of the FAA, other agencies, professional groups, and the aviation community on social and environmental factors affecting airport development.

2.1.4.5 Flight Standards Service (AFS)

The Flight Standards Service promotes the safety of flight of civil aircraft in air commerce by setting certification standards and directing, managing, and executing certification, inspection, and surveillance activities to assure the adequacy of flight procedures, operating methods, and airmen qualification and proficiency. Their responsibilities include the following:

- developing, evaluating, and approving or disapproving concepts, standards, equipment, and flight procedures related to aircraft noise abatement;
- developing concepts, rules, standards, and criteria governing the operational aspects of en route, terminal area, and instrument flight procedures (except air traffic control procedures); and
- serving as the Rotorcraft National Resource Specialist (AFS-804) and leading the Rotorcraft Task Force that deals with rotorcraft operations and maintenance matters.

2.1.4.6 Air Traffic Rules and Procedures Service (ATP)

The Air Traffic Rules and Procedures Service is the principal office in the FAA with respect to air traffic control (ATC) regulations and procedures for civil and military air traffic, and designation of the utilization of navigable airspace. Their responsibilities include the following:

- developing and approving policies and issuing procedures, criteria, and separation standards that may be required to provide ATC and communications services to domestic and international air traffic services;
- serving as the focal point within the agency for reviewing and evaluating user requirements concerning air traffic procedures, criteria, and operating

instructions, and for the coordination of such items with the appropriate offices;
- o developing and recommending policy and procedures associated with the provision of air traffic services within domestic airspace and those portions of international airspace for which the United States has responsibility; and
- o developing national standards and procedures for the administration of environmental guidelines and orders as they apply to air traffic procedures in navigable airspace.

2.2 SUPPORTING RESEARCH INSTITUTIONS

While the FAA's major role in vertical flight noise R&D is one of regulatory oversight and infrastructure development, there are other organizations whose primary interest is conducting research into promising technical design areas that may enhance performance and reduce technical risk, such as aircraft design, acoustics, aerodynamics, enabling flight and safety systems, and propulsion. There are also organizations that support research by assisting the government in effectively carrying out their functions. These organizations are listed in the following sections.

2.2.1 National Aeronautics and Space Administration (NASA)

As the agency responsible for conducting theoretical, experimental, and computational research on advanced aeronautical concepts, NASA's activities in vertical flight noise R&D span virtually the entire range of rotorcraft aeromechanics, including dynamics, design, handling qualities, human factors, simulation, and flight test. The Office of Aeronautics Exploration and Technology (OAET) at NASA Headquarters, in conjunction with the three research centers at Langley, Ames, and Lewis, is playing an instrumental role in planning for safe, economical, and environmentally acceptable vertical flight aircraft. NASA's Advanced Tiltrotor Transport Technology (AT^3) Program, currently in the planning stages, is to be a coordinated agency-wide effort. The organizations within NASA involved in vertical flight noise R&D are listed below.

Office of Aeronautics Exploration and Technology
- o Aeronautics Directorate (Program Management)
- o Aerodynamics Division
- o Information Sciences and Human Factors Division
- o Materials and Structures Division
- o Propulsion, Power and Energy Division

Ames Research Center
- o Aerospace Systems Directorate (Program Technical Management)

- Aircraft Technology Division
- Flight Systems and Simulation and Research Division
- Full-Scale Aerodynamics Research Division
- Fluid Dynamics Division
- Aerospace Human Factors Research Division

Langley Research Center
- Acoustics Division
- Structural Dynamics Division
- Applied Aerodynamics Division

Lewis Research Center
- Propulsion Systems Division
- Aeropropulsion Analysis Office

2.2.2 U.S. Military Services

The U.S. Army is the lead military service for DOD vertical flight R&D programs. Its research focus is on highly maneuverable, low observable technology, which is driven by military mission requirements as well as by fly-neighborly concepts. The military mission requirements include deep penetration and clandestine operations. Fly-neighborly concepts include training pilots and modifying flight operations in populated areas for reducing noise impacts on the community. U.S. Army organizations involved in vertical flight noise R&D include the Aeroflightdynamics Directorate (AFDD) and Aerostructures Directorate of the Aviation Systems Command (AVSCOM), and the Corps of Engineers Construction Engineering Research Laboratory (CERL).

The Naval Air Systems Command (NAVAIR) is currently developing the V-22 Osprey to satisfy specific mission requirements, including amphibious assault, resupply of forward-deployed forces, combat search and rescue, antisubmarine warfare, long-range special operations, and deployment to an overseas theater. To support these requirements, issues such as survivability, speed, range, maintainability, and operational flexibility are of prime importance to the military. R&D on noise-related issues is not a high priority in the ongoing developmental test program, nor is it expected to be during the operational test program.

2.2.3 Universities

Academic institutions are also supporting vertical flight noise R&D, although they are usually focused more on long-term, pure and applied research intended to further understanding of basic phenomena. Cornell University has obtained excellent results using a very simple, low speed tiltrotor model to study the behavior of fountain effects. The Georgia Institute of Technology is developing computational fluid dynamics (CFD) codes and is building a small high speed (supersonic tip Mach number)

tiltrotor system. Both flow and acoustic data will be acquired from this model. Research at both universities is likely to produce important data and findings crucial to understanding the physics of tiltrotor noise.

As the vertical flight noise R&D program progresses, academic involvement will hopefully increase through government and industry grants awarded to conduct research on relevant topics. Areas where university participation could make a sizable contribution include development of innovative solutions for noise instrumentation in the cockpit and active suppression of internal noise; development of all-inclusive code and computer simulation of flight paths, flow around the vehicle, vehicle component vibration, acoustic wave visualization, and noise footprints; prediction of vortex size, strength, and dissipation from first principles; and participation with NASA at the research centers listed in section 2.2.1.

2.2.4 Support Contractors

Administrative support and coordination are provided largely by contractors specializing in systems engineering, technical assistance, and program management support. Their services to the government in support of noise R&D include integration/coordination of FAA efforts with those of other agencies, organizations, and local communities and governments; preparation of documentation, including tools to facilitate budget allocation; preparation and execution of meetings; and technical and management support of working groups.

2.3 MANUFACTURER INVOLVEMENT

Vertical flight aircraft manufacturer participation is a critical element for successful noise R&D, since the goal of ensuring quieter, more acceptable vertical flight aircraft must be met if these companies are to produce economically competitive products. The more acceptable new vertical flight vehicles are to the public, the more profitable the market will be for those vehicles. Thus, manufacturers have a strong motivation for conducting research on such issues as human response to noise, potential community impact of vertical flight noise, active noise control techniques, advanced blade designs and tip configurations, and ensuring that the aircraft is capable of performing operating procedures that minimize noise in the vertiport environment. In addition, manufacturers are strongly supportive of efforts to develop simplified certification procedures for conventional rotorcraft and to begin developing a new noise certification regulation for tiltrotors and other AVF aircraft, since serious designs of such aircraft require known noise goals. If government and industry coordinate their efforts in this area, significant time and resources will be saved.

To date, U.S. manufacturers who have full-scale tiltrotor hardware are Bell Helicopter Textron Inc. (BHTI) and Boeing Defense and Space Group, Helicopters Division. It is expected that these two companies will remain partners on the military version of the tiltrotor (the V-22 Osprey) and will share equal responsibility and all data. For a civil version of the tiltrotor, these two companies are likely to compete against each other. United Technologies Sikorsky Aircraft is also involved at the conceptual design stage and is examining a variable-diameter rotor concept. McDonnell Douglas Helicopters has also recently started to examine new tiltrotor concepts.

Five European governments, including France, Germany, Italy, Spain, and England, have formed a consortium (European Future Advanced Rotorcraft (EUROFAR)) to investigate the feasibility of developing a commercial tiltrotor aircraft design. The EUROFAR program is being conducted by Agusta, Eurocopter, Westland Helicopters, and Construcciones Aeronauticas SA (CASA). Work is now underway in areas such as aerodynamics, handling qualities, structural design criteria, and acoustics. Westland Helicopters has also been involved in vertical flight noise R&D during development of their EH101 helicopter. Their main emphasis at present is aeroacoustics of main rotors with particular focus on the acoustic signature generated by high performance blades in high speed flight.

The Ishida Group, a Japanese corporation headquartered in Fort Worth, Texas, is pursuing design and development of a tiltwing aircraft, the TW-68. Ishida expects certification to take place in 1997, with production deliveries to follow shortly thereafter.

3.0 STATUS OF CURRENT VERTICAL FLIGHT NOISE R&D

Research and development in the area of vertical flight noise are being conducted by government, industry, and academia to address a wide spectrum of issues. The current status of this research is described in the following sections.

3.1 NOISE R&D BY THE FEDERAL GOVERNMENT

3.1.1 Federal Aviation Administration

3.1.1.1 Office of Environment and Energy

AEE is in the process of updating the Heliport Noise Model (HNM) to version 2 to incorporate improved and expanded rotorcraft data, and more reliable software. AEE is also presently pursuing research directed at simplifying the present helicopter noise certification procedures prescribed under 14 CFR 36 and ICAO annex 16 in support of the development of positions for the United States at ongoing ICAO deliberations. Research is planned that will provide advanced analytical procedures and other methodologies for addressing the "acoustic change" analyses associated with a change in helicopter type design. These procedures are intended to reduce and potentially eliminate requirements for conducting a complete noise flight test for rotorcraft which are potentially noisier as a result of a change in type design. The procedures to be developed will assist in calculating the acoustic impact of a change in type design in lieu of a noise test. Research is planned that will advance the availability of noise abatement technology for rotorcraft in anticipation of more stringent noise certification requirements in the future. Research is also planned for assessing the available noise abatement technology for AVF aircraft and for developing noise certification procedures for such aircraft.

3.1.1.2 Vertical Flight Program Office

In March 1991, the VFPO sponsored a workshop at the Georgia Institute of Technology to investigate tiltrotor noise. The workshop had two major objectives: (1) to review the status of research and development in predicting and reducing tiltrotor noise, and (2) to identify key technical and operational issues and methods to address them. The second objective has both near and far term implications. In the near term, the goal of addressing such issues is to arrive at a level of technical credibility that can support decisions to develop urban and inner city markets for tiltrotors. The longer term goal of identifying technical and operational issues is to target resources and actions which could lead to tiltrotor noise abatement and effective control.

Since this initial workshop was held, the emphasis of the noise efforts undertaken by the VFPO has been expanded to include all vertical flight aircraft. It is anticipated that after publication and dissemination of this document, a second workshop will be held to further define the issues and requirements identified here and to provide additional details on projects to be undertaken in the future.

The VFPO, in conjunction with NASA and industry, has recently prepared a plan to develop vertical flight instrument flight rules (IFR) terminal area procedures (VERTAPS). This planned R&D effort has three primary objectives:

- to identify and define the terminal airspace procedures required to support vertical flight operations in instrument meteorological conditions;
- to develop a systems plan that, when executed, will provide knowledge and data to help develop a network of IFR vertiports, both free-standing and collocated with major congested airports; and
- to enhance the capabilities and efficiency of terminal instrument procedures (TERPS) criteria development through combined use of simulation and flight test validation.

An important element to be addressed in the VERTAPS program is the use of operational procedures for noise abatement in the terminal environment, and for enhancing acceptable vertical flight operations in the NAS. Such procedures could include steep angle approaches and departures; specific corridors for transitioning from the en route to terminal phase of flight; and optimized combinations of nacelle tilt, airspeed, and altitude to promote quieter operations. Procedures will be designed initially through simulation, followed by validation through flight test. Noise models based on existing acoustic data will be used during simulation to project noise footprints onto the terminal area groundplane, providing a relative measure of community acceptance and forming the basis for discrimination among candidate flight profiles.

3.1.2 NASA

The NASA AT^3 Program is currently being formulated as a new agency-wide initiative in high speed civil rotorcraft. The objective of the program is to provide U.S. industry with the validated systems technology required for developing an advanced, commercial tiltrotor transport early in the next century. There are three goals for this planned program:

- to overcome barriers to community and passenger acceptance through noise and vibration reduction,

- to achieve civil transport levels of safety for flight systems, and
- to achieve commercial levels of vehicle economy and efficiency.

NASA's ongoing and planned tiltrotor flight research program to validate specific technologies and methodologies that require flight to reduce technical risk is designed to support these AT^3 Program goals. In the near future, this will include studies of terminal area acoustics, acoustic performance (both in hover and in flight), airloads testing, and controls/displays requirements.

Technology developed under the AT^3 Program will build on NASA's ongoing research and technology programs and will benefit conventional rotorcraft as well as AVF aircraft in both civil and military missions.

3.1.2.1 <u>NASA Langley Research Center</u>

Much of NASA Langley's R&D efforts are in the areas of noise prediction code development and noise control for vertical flight aircraft. The status of these efforts, including accomplishments to date, is as follows:

Noise Prediction Code

- development of CFD-based codes to predict rotor noise that includes fountain effect in hover and propeller/spinner interacting in cruise,
- development of qualitative blade vortex interaction (BVI) prediction code for estimation of rotor noise,
- development of quantitative BVI prediction codes with physics modelling, and
- validation of far-field noise prediction codes using measured blade pressure data as input.

Noise Control

- demonstration of active control of interior noise from an exterior source with a model fuselage, and
- completion of Phase I of active flap control of BVI noise and initiation of the Phase II experimental program.

NASA Langley's programs primarily concentrate on noise characterization and code validation in flight test activities. There are currently two active programs in these areas. A joint effort with NASA Ames Research Center using a highly instrumented UH-60 helicopter has been designed to provide data for validation of new and developing noise prediction methods by using measured loads on the rotor blades as input. Another joint effort with NASA Ames Research Center involves the XV-15 tiltrotor research aircraft. Two successful flight test programs were conducted during 1991 using this aircraft. One program involved hover

tests at Moffett Field, and the other program, conducted at Crow's Landing, examined forward flight acoustics, particularly terminal area characteristics. The results of the hover test were documented at the American Helicopter Society (AHS) Specialists Meeting in Philadelphia in October 1991 (reference 3), and some of the results of the forward flight test were prepared for presentation at the AHS Forum in Washington, D.C. in June 1992 (reference 4).

3.1.2.2 NASA Ames Research Center

Current activities in vertical flight noise research at NASA Ames are focusing on tiltrotor acoustics. Recent activities in this area include:

- completion of comprehensive acoustic tests in hover and preliminary acoustic tests in terminal area operations with the XV-15 tiltrotor aircraft, outfitted with highly-twisted, composite advanced technology blades (ATB);
- initiation of design and development of a tiltrotor aeroacoustics model (TRAM) for quarter scale semi-span and full-span hover and wind tunnel testing (in cooperation with the U.S. Army Aeroflightdynamics Directorate (AFDD) and NASA Langley Research Center);
- development of a large-scale tiltrotor test rig for use in conducting rotor performance and aeroacoustic wind tunnel tests of tiltrotor aircraft proprotors; and
- other work that supports noise reduction efforts, including hover download reduction, tiltrotor airworthiness criteria development, and active control studies.

3.1.3 Naval Air Systems Command (NAVAIR)

The Naval Air Systems Command is continuing the developmental test program for the V-22 Osprey tiltrotor. The revised test schedule is currently being solidified. However, noise is not a top priority for the military, and no comprehensive noise tests are planned. Preliminary fly-by data was obtained by BHTI in previous flight tests but was of limited use. To remedy the lack of a V-22 noise database, NASA, in conjunction with the FAA, is investigating the possibility of obtaining aircraft time from NAVAIR to conduct a joint V-22 noise flight test program. These tests would complement ongoing V-22 developmental testing for military applications, as well as providing an acoustic database for civil applications. Both external and internal acoustic characteristics would be assessed, terminal area operations and vertiport issues would be addressed, and developing acoustic prediction methodologies would be supported. At the present time, there are no conclusive plans for obtaining the V-22 for such a test.

3.1.4 U.S. Army Aeroflightdynamics Directorate (AFDD)

The Army's commitment to conducting R&D in vertical flight acoustics has led to major strides in the identification and understanding of noise sources, development of high quality aeroacoustic databases, development and validation of computational codes for design tools, and advanced concepts to reduce/control noise radiation.

The Fluid Dynamics Division at AFDD, located at NASA Ames Research Center, is pursuing CFD research aimed at improving computer simulation technology. Mission requirements for the V-22 call for deep penetration effectiveness and clandestine operations. Computer modeling of low noise designs is being used in support of these requirements. Wind tunnel validation has included Boeing Helicopter's 360 rotor system, McDonnell Douglas's Harp blade, and the Sikorsky/United Technologies Research Center UH-60A with British Experiment Rotor Program (BERP) tips for reduced noise and increased flexibility.

In cooperation with NASA Ames and NASA Langley Research Centers, AFDD is also conducting the TRAM program, as described in section 3.1.2.2. The primary objective of this program is to build a quarter-scale wind tunnel model of a tiltrotor aircraft for further advancement of innovative technology concepts. Aeroacoustic wind tunnel tests are planned at several NASA wind tunnels and at the European Duits-Nederlandse wind tunnel (DNW).

3.1.5 U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL)

Researchers at CERL are conducting research in the areas of sound propagation, active noise control, beam-forming arrays for imaging acoustical fields, low-frequency sound attenuation, noise mitigation barriers, and minimization of community noise through flight path optimization. These researchers are approaching active noise control methodologies from the viewpoint of shielding the community from helicopter noise during warm-up. They are also examining operational noise data for Army helicopters for flyovers, ascent, descent, hover, and zero-pitch idle. Although conducted with military vehicles, results from these studies are considered directly applicable to civil use of vertical flight aircraft.

3.2 NOISE R&D BY MANUFACTURERS

3.2.1 Boeing Defense and Space Group, Helicopters Division

Researchers at Boeing are currently assessing the accuracy of their helicopter noise prediction methodology when applied to tiltrotors. A limited amount of XV-15 test data will be used in the study. Depending on the results, additional prediction

procedures may be developed for tiltrotor noise. Boeing researchers also plan to assess the potential impact of vertical flight noise on the community.

3.2.2 Bell Helicopter Textron Inc.

BHTI efforts in the area of tiltrotor acoustics involve research into both external and interior (crew/passenger area) noise control. Emphasis of the external noise research efforts has been on compiling a database, defining primary noise characteristics, developing a noise contour prediction model, identifying noise abatement operational procedures unique to tiltrotors, and assessing noise certification criteria appropriate to this class of aircraft. Emphasis of the interior noise control efforts has been on identifying major noise sources; defining these sources' sound levels, frequency content, and spatial distribution throughout the cabin; establishing the noise reduction needed; and developing efficient minimum-weight soundproofing concepts and treatments.

Accomplishments to date include:

- initial documentation of low noise features unique to tiltrotor aircraft, based on flight test noise measurements of the XV-15;
- determination of maximum and minimum noise emission regions within the XV-15 flight envelope and identification of quiet operating modes, based on additional flight test noise measurements;
- estimation of noise levels for a family of tiltrotor aircraft up to the 49,000 pound size V-22 Osprey;
- completion of the first extensive internal noise survey inside a tiltrotor aircraft which revealed major noise sources, their levels and frequency content, and the spatial distribution of noise throughout crew and passenger areas; and
- development of a tiltrotor noise contour prediction code which takes into account aircraft design changes, segmented flight trajectories, operational variables, and different community noise impact criteria.

3.3 NOISE R&D BY ACADEMIA

3.3.1 Cornell University

Researchers at Cornell University, under a grant from NASA Ames Research Center, have fabricated and tested a small-scale, full-span tiltrotor model. The purpose of this study is to investigate the effect of rotor hover downwash (the so-called "fountain effect") on the radiated noise field in hover. Analytical and computational studies of fountain and BVI rotor noise near the rotor plane are also being conducted.

3.3.2 Georgia Institute of Technology

Researchers at Georgia Institute of Technology, under a contract from NASA Langley Research Center, are developing research-oriented CFD methodologies and codes for the prediction of tiltrotor acoustics. In support of these efforts, the following tasks are being performed.

Three-dimensional (3-D) Euler Propeller BVI Code - Modification of an existing 3-D Euler propeller code to include BVI aerodynamic modeling. The resulting code will have the capability of modeling single and dual rotating propellers, as well as a forebody and nacelle. Propeller tilt will be modeled using flow angle of attack so that BVI at various static tilt angles may be assessed. Vortex effects will be modeled using a velocity transpiration approach.

3-D Euler/Navier-Stokes Hovering Tiltrotor Code - Development of a specialized multi-zone CFD method from existing rotary-wing codes to study the aerodynamics/aeroacoustics of a hovering tiltrotor. The propeller code described above will handle the rotor/shaft/wing zone. The code and grid generation scheme will be modified to accommodate insertion of a wing as a boundary. This code will be loosely coupled with another Euler/Navier-Stokes code (GTNS3D), which will handle the remaining zones of the computational domain exclusive of the rotor/shaft. Coupling will involve codes for both the propeller and fixed-wing zones, and will consist of updates after a set number of iterations are run for each zone.

Experimental Support - Acquisition of flow visualization data using a simple model tiltrotor to support selected CFD computations. This is to be done at low tip speeds using two, three-bladed rotors appropriately assembled to simulate a tiltrotor system.

3.3.3 University of Bristol (U.K.)

The University of Bristol is a participant in the Helinoise program funded by the European Community (EC) to study helicopter noise reduction. In this program, they are conducting modeling and prediction efforts, including direct acoustic modeling and comparison with experiment, and development of more accurate rotor wake models for use in acoustic prediction.

The University of Bristol is also involved in two other EC programs in rotor aerodynamics. The first involves development of an accurate predictive capability for transonic 3-D flow on rotor blades. University researchers are using an improved Euler method which offers an order of magnitude increase in both accuracy and computation time through use of advanced algorithms. The second program is a study of interactional aerodynamics, in

particular the problems of vortex surface interactions. This is an area in which physically unrepresentative invasion of the surface occurs in many existing computational methods. A new method has been found which allows accurate and physically realistic computation of this problem. Both of these studies emphasize the importance of good aerodynamic predictions in acoustic modeling.

Another study is in progress on the dynamic measurement of rotor wake position using visualization. Shadowgraph, smoke, and laser light sheet visualizations are used. This work is done to provide better understanding of the wake interaction processes on a rotor.

Two separate studies are in progress on the effect of the rotor boundary layer on rotor flows. There is considerable evidence that the assumed flows on the rotor are significantly affected by centrifugal actions within the rotor boundary layer. This leads to useful increases in overall performance, but is also a potentially important mechanism which must be included in any acoustic prediction method. A theoretical study combines a full panel method prediction for the rotor (including a new asymptotic wake model) with a new 3-D boundary layer prediction designed to interface directly with the method. A separate experimental study is in progress using surface visualizations, a new blade section flow visualization method, and measurements using an advanced 3-D fiber optic laser Doppler anemometer. This has demonstrated significant 3-D effects in the rotor flows.

Studies of the acoustic effects of interactions between turbulence and the rotor are being undertaken. The importance of this source has been inadequately recognized. Work undertaken so far has demonstrated that previous models of the process may be misleading and that practical effects resulting from flight in a real atmosphere are underestimated. These issues are of considerable potential significance for vertical flight aircraft design and operations.

3.3.4 University of Cambridge (U.K.)

A model for propeller noise prediction has been developed at the University of Cambridge. The model uses asymptotic theory to predict the near-field and community noise from propellers. This methodology provides a practical and accurate scheme for further evaluation of propeller noise mechanisms. It also requires much less computational capability than existing prediction modules. Further development of this method will include propeller and wing interaction noise.

4.0 ISSUES AND CONSTRAINTS

In order to successfully pursue the goal of producing quieter, more acceptable vertical flight aircraft, research and development must attempt to resolve noise issues in four major areas. These issues are described in the following sections.

4.1 TECHNICAL

Developing and validating innovative technologies for cost-effective, highly efficient, low noise aircraft designs is the overall focus of this R&D area. A design-for-noise methodology for vertical flight aircraft would not only reduce technical risk for manufacturers but would also address the problem of community acceptance early in the design process.

4.1.1 Noise Generation

4.1.1.1 Blade Vortex Interaction

The tiltrotor is expected to have twice the disc loading of a typical helicopter, hence a considerably higher proprotor tip speed. This will produce particularly intense BVI noise. Much work on BVI noise has been done, but this work has either been of a fundamental nature or specific to helicopters.

Understanding BVI is the most critical component in resolving tiltrotor noise issues. It is the biggest challenge in the prediction of noise, perhaps the one that holds the key to making the tiltrotor acceptably quiet. However, it is difficult with the current state-of-the-art to predict the position and the strength of a tip vortex. These aerodynamic parameters must be understood and predicted before BVI acoustics can be modeled correctly.

Research should be focused on how tiltrotor BVI is affected by design and operational variables such as blade twist, blade number, solidity, nacelle angle, and descent rate. In addition, the evolution of rotor blade trailing vortex formation and diffusion, with and without BVI, must be better understood.

4.1.1.2 Fountain Effect

Another key issue related to tiltrotor noise generation that is not yet understood is the noise due to fountain effect, produced by interaction of the upwash between the rotor discs and the wings. This can produce higher levels of fluctuating force on the rotor blades and lead to high noise levels. A better understanding of fountain flow is needed, including how it affects hover noise and how it can be modified aerodynamically.

4.1.1.3 Turbulent Interaction with the Rotor

Although the potential significance of this noise source is recognized, some researchers believe it may have been given inadequate priority. There is reasonable evidence that turbulent input to the rotor may well be the dominant source of noise on a rotor designed to be quiet. The operating environment may contain turbulent air in several important circumstances, i.e., low-wind conditions when the turbulence is generated by thermal effects, and in city center operations where turbulence may be caused by the wake from surrounding buildings. Most experiments involving rotors are performed in a carefully controlled environment with minimum turbulence, such as a wind tunnel. There is a serious concern that such experiments could be misleading unless proper allowances for the effects of atmospheric turbulence are included.

4.1.1.4 Vortex Breakdown Effects

There is clear evidence from work in the United States and the United Kingdom that at disc loadings typical of tiltrotor aircraft, the wake vortices undergo breakdown. This effect is not included in any prediction or design method, and is a potentially significant contributor to rotor noise. If the phenomenon were well understood, there is the possibility that vortex breakdown effects could be used to reduce BVI noise.

4.1.2 Noise Propagation

The state-of-the-art in modeling sound propagation does not adequately handle atmospheric turbulence. In spite of continued efforts in this area, researchers studying sound propagation do not yet possess an all-encompassing model. In particular, the propagation of low-frequency noise is not well understood. Its impact on en route noise still needs to be determined.

4.1.3 Noise Prediction

Vertical flight noise prediction capability is progressing well but is currently limited by the accuracy of current predictions of BVI and other complex flow interactions. There is a continuing need to improve prediction models in this area.

A collection of accurate benchmark aerodynamic and acoustic data for model and full-scale tiltrotors is needed to test analytical and computational prediction methods. It would be advantageous during future full-scale acoustic data acquisition if researchers working on noise prediction were consulted concerning their requirements for data.

4.1.4 Noise Reduction

Continued research is needed to reduce both interior and far field noise. It is difficult to generalize design requirements for reduced rotor noise, because the acoustic output varies so widely depending on noise source, flight condition, measurement location, and frequency range. However, assuming the rotor must lift a fixed nominal payload and operate over a wide range of flight conditions, three general design guidelines can be stated: (1) minimize tip Mach number, (2) minimize blade thickness in the tip region, and (3) minimize gradients in the spanwise lift distribution in the tip region. The first two guidelines are aimed at minimizing thickness noise and high speed impulsive noise. The third guideline is aimed at minimizing the tip vortex strength, and thus BVI noise.

A number of concepts have been proposed to reduce tiltrotor aircraft noise. They include increased spacing of fuselage/proprotor, active control techniques, low noise blade/tip configurations, improved airfoil shape, increased number of blades, tip vortex diffusion devices, reduced tip speed, blade planform, and variable diameter blades. A systematic study needs to be conducted to evaluate and rank these and other methods of controlling tiltrotor noise. The study needs to include cost/benefit and risk assessments.

The value of active control technology has been demonstrated in diverse aerospace applications which include active aeroelastic control, gust alleviation, and vibration suppression. Higher harmonic control (HHC), first developed for suppression of helicopter vibrations, is perhaps the most prominent rotorcraft example. HHC technology, which supplements the usual swashplate configuration with higher harmonic control inputs, has been successfully applied on an OH-6A helicopter, demonstrating dramatic suppression of vibration at the pilot's seat via modest feathering inputs to the blades at harmonic frequencies of the rotor speed. However, because the traditional swashplate assembly is employed, each blade is constrained to follow an identical pitch angle schedule as a function of blade azimuth, which limits the control to discrete frequency inputs. This pitch variation limitation prevents the introduction of more complicated control patterns in the rotating system.

More recently, researchers have studied and tested the potential of more versatile active control approaches (reference 5). Control mechanisms have been introduced into the rotating system so that subharmonic, as well as nonharmonic, control inputs can be effected. Controller implementations which have been investigated include the mechanical servo flap, jet flap, circulation control, and independent blade root pitch change configurations. Unlike HHC, which is limited to particular discrete frequency disturbance suppression, these individual

blade control (IBC) configurations constitute a broad band approach to rotor blade control. One barrier that stands in the way of many IBC concepts at present is the problem of hardware implementation. It is difficult at best to achieve an efficient rotor design when hydraulic or electromechanical actuators are introduced into the rotating system.

On a completely separate front, researchers in the field of structures and structural dynamics have made great progress in defining, developing, and analyzing what are now termed "smart structures." Also known as adaptive, or intelligent structures, their general characteristics may include the ability to adjust to changed conditions or the capability to deform their geometry as required. Their makeup may include embedded or bonded sensors and actuators that are in turn constructed using a combination of "smart materials" and feedback control. Most of the smart structures developed to date employ either piezoelectric devices, shape memory alloys, electro-rheological fluids, or electrostrictive materials. This technology has matured so that it is now possible to design a rotor blade, constructed in part with smart materials, that can respond to external stimuli or feedback control signals and adapt its geometry to changing conditions. Such technology should be used to its fullest to control the noise produced by vertical flight aircraft.

The combination of individual blade control concepts and emerging technology for blade actuation using smart materials could revolutionize rotor design in the disciplines of performance, dynamics, and acoustics. Current rotor designs necessarily represent a difficult trade-off between hover and high speed performance, and between performance and other design criteria such as interior noise and far field signature level. Active control technology has the potential to improve rotor design by relaxing the trade-offs required to some degree. By introducing additional freedom for rotor control (i.e., active control of rotor speed, individual control of blade pitch, limited control of airfoil shape, at least over some portion of the blade's span, and even control of spanwise blade properties), dramatic improvements in rotor vibration, performance, and noise generation may be possible. Control inputs could even be tailored to specific operating conditions. For instance, when in a highly populated area, one could actively reduce noise levels, at the price of performance, to meet noise regulations. Alternately, one could choose to maximize performance in flight regimes where higher noise levels are acceptable.

There are practical limits to reduction of rotor noise through active control. For instance, as pointed out in reference 5, noise due to the generation of lift cannot be eliminated since lift is required for flight. However, active controls may allow the designer flexibility in distribution of radiated lift noise about the rotor azimuth. Thus, it may be possible to redirect

some portion of the lift noise to improve overall far field noise signature. Furthermore, introducing controls to produce a more even distribution of lift along the blade span may be beneficial.

4.1.5 Noise Modeling

How well model data compares with full-scale data for a tiltrotor aircraft is still an open issue. There is evidence to indicate that model-scale data displays an unusually large number of higher harmonics that are not seen in full-scale data. The reason for this needs to be investigated.

4.1.6 Wind Tunnel Simulation

Currently, accurate wind tunnel simulations cannot be performed because most wind tunnels are not treated to absorb sound at very low frequencies typical of these aircraft. This is particularly true of the 40 by 80 feet and 40 by 120 feet test sections at NASA Ames Research Center.

4.1.7 Interior Noise

Acceptable interior noise levels are crucial to passenger acceptance and have become increasingly important in determining the marketability of aircraft. With the advent of AVF aircraft, passengers will expect quiet, comfortable transportation that is at least comparable to that of fixed-wing commuter and transport aircraft.

A tiltrotor has flight characteristics of both rotary- and fixed-wing aircraft, resulting in the need to address internal noise characteristics which are typical of both types of aircraft. In order to control tiltrotor interior noise, BHTI's approach using the XV-15 has been "to first understand its makeup in terms of frequency content, amplitude, spatial distribution throughout the cabin, and sound propagation paths. Once the makeup is understood, then appropriate measures can be taken to treat the interior" (reference 6). Passive techniques have been studied, but found generally to be unacceptable due to the adverse effects of added weight on aircraft performance. Active control of interior noise has therefore received increased emphasis as an effective, lightweight, noise reduction method.

The dominance of very low frequency noise in the tiltrotor noise spectrum is a major concern. Because the noise frequency in the V-22 is two octaves lower than most turboprops, cabin noise levels on the order of 78 to 85 decibels (dB) (typical for commuter or short-range aircraft) may not be appropriate, and experimental research is required to establish acceptable noise levels for very low frequencies. Interior noise and vibration control technology needs to be verified in three modes (hover, transition, and cruise) during V-22 flight testing. However,

since a civil tiltrotor (CTR) would spend the majority of its flight time in cruise flight, the noise characteristics in that mode are of particular importance.

4.2 OPERATIONAL

AVF aircraft could enter the commercial air transportation system by the turn of the century, helping to relieve airport congestion. While the areas affected by rotorcraft noise (noise footprints) normally are considerably smaller than those of fixed-wing aircraft, these footprints will increasingly occur in the vicinity of vertiports in heavily populated regions such as central business districts. Operations in these areas highlight the requirement for noise abatement solutions that will ensure compatibility with surrounding communities.

To reduce the negative impacts of vertical flight noise, government and industry must not only pursue the technological issues discussed in section 4.1, but also operational improvements. Designs for noise abatement, such as increasing the number of blades or implementing active noise control techniques, are largely long-term solutions to dealing with vertical flight aircraft noise, in other words, a challenge for the future. In the meantime, however, operational near-term solutions exist for abating community noise. These include following noise abatement profiles and routings in terminal areas, operating aircraft at reduced tip speed in hover and conversion, using flight trajectory management and vehicle configuration control, and developing low noise TERPS and ATC procedures using both simulation and flight vehicles.

In particular, AVF aircraft such as tiltrotors have unique operational features not shared by conventional helicopters that offer great potential for noise abatement. These include:

- low en route noise levels;
- a wide operations envelope;
- hover, takeoff, and approach noise levels typically lower than helicopters of comparable size;
- no highly directional, time-varying sound source (such as a tail rotor); and
- inherent flight trajectory management capability, wherein scheduling of the nacelle angle and airspeed may become a major operational variable affecting radiated noise.

Capitalizing on the operational flexibility of these aircraft in order to optimize noise reduction may help increase acceptance of vertical flight operations in the future.

4.2.1 Noise Abatement Profiles and Routings

Frequently, airlines and ATC have developed aircraft profiles to support noise abatement procedures, such as a three-segment departure procedure or a higher than minimum approach altitude prior to glideslope intercept. Noise abatement routings may involve the use of arrival and departure patterns over the least sensitive land use areas where feasible. Approach and departure procedures over water bodies and agricultural or open space corridors are usually designated. On the other hand, passenger comfort and acceptability are important considerations that may somewhat limit AVF aircraft to suboptimum noise abatement flight paths.

Use of noise abatement principles must be incorporated into operations planning to maximize quieter vertical flight operations. A list of sample planning factors to be considered when implementing flight profiles and routings for noise abatement is included below.

Terminal

1. Select approach/departure flight paths which avoid direct overflight of noise sensitive areas/facilities.
2. Plan approaches so that the loudest side of the aircraft (if one exists) is directed away from noise sensitive areas.
3. Plan departures directly away from the most noise sensitive area or facility.
4. Depart at steepest takeoff trajectory possible and quickly reach en route altitude.
5. Minimize lengthy low-speed near-hover transitions.
6. Avoid long periods at flight idle.
7. Reduce rotor speed to ground idle as quickly as possible after landing.
8. Avoid steeply banked turns.

En Route

1. Identify noise sensitive areas/facilities along routes, such as residential areas, schools, hospitals, churches, amphitheaters, etc.
2. Plan flights over high ambient noise corridors and open spaces, such as roadways, railways, and waterways.
3. Maintain maximum distance separation when bypassing noise sensitive areas.
4. Assign maximum altitudes practicable when transiting noise sensitive areas.

4.2.2 Flight Trajectory Management

In the last 10 years, various noise tests have been conducted by NASA and BHTI on the XV-15 tiltrotor to study the effects of

operational variables on external noise levels. These tests have included level-flight studies with airspeed, nacelle angle, and altitude variations, and takeoff and landing flight procedures representative of those that might be used in vertiport operations. Results have shown that low nacelle angles even at high forward speeds generate less noise than high nacelle angles. In addition, regions of maximum, moderate, and minimum noise within the XV-15 flight envelope have been identified (reference 7). Minimum noise regimes exist in about 60 percent of a tiltrotor's normal operating envelope. With knowledge of these regions, significant noise abatement is possible. Those operations involving transition between the helicopter and airplane modes can be planned to take full advantage of the minimum noise region of the tiltrotor's flight envelope. Also, automatic flight control systems may offer the opportunity to schedule nacelle angle and airspeed for optimal noise abatement.

Altitude selection is a major factor by which a pilot can reduce en route noise. This is particularly true in reducing noise exposure directly beneath the flight path and to the sidelines out to about 1,000 feet. While minimum altitudes necessary to satisfy all noise concerns cannot be generalized, an en route altitude of at least 1,000 feet results in near constant noise exposure to either sideline.

A methodology has recently been developed by BHTI to predict the impact of various operating modes on tiltrotor approach noise (reference 8). Results of these predictions illustrate the tiltrotor's effectiveness in minimizing noise impact through proper selection of airspeed and nacelle angle. The size of the noise footprint can be significantly reduced by flight trajectory management, i.e., by changing the airspeed/nacelle angle combination. Using this methodology, the XV-15 noise contour area was reduced by 30 percent by delaying conversion to helicopter mode. Predictions were also generated that could prove useful for tiltrotor predesign studies, showing the effects of gross weight and tip speed on noise produced. The next step will be to extend the capability of the methodology to additional flight conditions, particularly transition to hover.

4.2.3 Procedure Development

4.2.3.1 VERTAPS

As discussed in section 3.1.1.2, the FAA is pursuing a project to develop environmentally acceptable IFR terminal area procedures that will take advantage of the full potential of vertical flight aircraft within the next decade. As a cost-saving and time-saving measure, the procedure development process will validate simulation as the preferred method for future terminal instrument procedure development. Government, industry, and operator participation will ensure that procedures developed are

acceptable to, and representative of, all segments of the vertical flight community. As a major factor determining the acceptability and commercial viability of vertical flight operations, the noise impact of terminal area procedures will be of paramount importance in the VERTAPS program.

Historically, instrument procedures criteria development has been a multi-year process that has not begun until a certified aircraft is available to generate actual flight data. This extensive and time-intensive data collection process could adversely affect the timely development of a safe, commercially viable, IFR system until well after AVF aircraft such as tiltrotors are produced, and may ultimately obviate production. Further, since a vertical flight IFR infrastructure will most likely influence vehicle and equipment design, lead time awareness of design factors is essential if manufacturers are to incorporate these requirements into their baseline designs. The goal of this project is to validate simulation as a reliable and effective tool for instrument procedure development as an alternative to the traditional flight test method.

The VERTAPS program will include development of criteria for vertical flight instrument procedures (VFIPs) and development of unique ATC procedures to incorporate vertical flight aircraft into the NAS. These procedures must permit fixed-wing and vertical flight aircraft to operate simultaneously without conflict. Procedural areas to be addressed include:

- innovative flight profiles that minimize airspace requirements and noise impact,
- procedure design rules,
- operating minima,
- obstacle clearance criteria,
- transition from en route to terminal control,
- approach/departure procedures (particularly steep angle capability),
- human factors, and
- timing and spacing requirements.

4.2.3.2 Noise Abatement Approaches/Departures

Procedures to reduce vertical flight aircraft noise should embody the noise abatement principles discussed in sections 4.2.1 and 4.2.2, as well as piloting/operational techniques that avoid the flight regimes of intense rotor BVI. Both landing speed and descent rate can be selected to mitigate the impulsiveness of the resultant acoustic signal. Tests have shown that reductions in noise exposure up to 5 dB are possible using such techniques.

In a noise test program of eight helicopters conducted jointly by the FAA and HAI, three operational variations of approach procedures were evaluated (reference 9):

- constant airspeed/constant glideslope,
- decelerating airspeed/constant glideslope, and
- decelerating airspeed/variable glideslope.

The third variation was preferred for noise abatement, since it is most similar to a normal approach. Such a procedure was shown to be effective for four of the eight helicopters tested. However, pilot familiarization with the noise abatement procedure appropriate to each helicopter is required. A procedure involving constant or near-constant glideslopes, coupled with either low constant airspeeds or decelerating airspeeds, was also found to be beneficial. This optional procedure is applicable where instrument landing systems or similar landing aids are available. Descriptions of the preferred and optional noise abatement approach procedures used in these tests are included below.

Preferred (7-10 degree approach profiles)

1. Start descent at 10-15 knots faster than normal.
2. Continually reduce airspeed during descent while maintaining comfortable rate of descent.
3. "Tune out" main rotor noise by keeping rotor torque as low as practicable.
4. During final portion of approach, increase collective and adjust ground speed for normal termination.

Optional (4-6 degree approach profiles)

1. Start descent at normal approach airspeeds.
2. Transition through high rotor noise regime as rapidly as possible.
3. Maintain comfortable rate of descent at minimum recommended approach speed.
4. During final portion of approach, increase collective and adjust ground speed for normal termination.

Two piloted simulation experiments have been conducted in the NASA Ames Research Center Vertical Motion Simulator to investigate instrument approaches on steep glideslopes for CTR aircraft. These tests were done largely to evaluate issues such as control/display technology, pilot workload, glideslope tracking performance, and cockpit field-of-view. However, these are all enabling factors that could significantly impact the feasibility of conducting steep approaches, which will in turn reduce the noise footprint and environmental impact produced by vertical flight aircraft in the terminal area.

With regard to takeoffs, the specific procedures used and resulting flight profiles depend on an aircraft's loading, performance capabilities, and prevailing conditions at the takeoff site (obstacles, wind, etc.). Likewise, the noise

associated with these takeoffs is dependent on the procedures used and the resulting flight profile. As a general rule, vertical flight aircraft noise on takeoff may be minimized by climbing to cruise altitude as steeply and quickly as possible. The capability to do this, however, is dependent on an individual aircraft's climb performance; hence, takeoff procedures for reduced noise are largely configuration specific.

4.3 REGULATORY

There are numerous regulatory issues related to vertical flight noise, applicable in the United States and internationally. Regulatory issues pertain to either or both of two sections of the Federal Aviation Regulations (FARs), those dealing with 14 CFR 36 (Airworthiness Certification) and those dealing with 14 CFR 150 (Airport Noise Compatibility Planning). These issues are discussed in the following paragraphs.

4.3.1 AVF Aircraft Noise Certification Requirements

Noise regulations were first applied to vertical flight aircraft in the 1980s through the adoption of chapter 8, "Helicopters," of ICAO annex 16 (International Standards and Recommended Practices -- Environmental Protection). This ICAO standard has become the basis for the regulations of many nations, including the United States's 14 CFR 36-H (Noise Standards: Aircraft Type and Airworthiness Certification, subpart H, Noise Requirements for Helicopters). The most important issues relating to 14 CFR 36-H are:

- developing noise certification requirements for AVF aircraft,
- reducing the complexity and cost of noise certification for all vertical flight aircraft,
- developing standardized noise regulations among the United States and foreign countries,
- investigating whether current noise certification metrics adequately address AVF aircraft noise and community acceptance criteria, and
- investigating the possibility of using computer simulation tools in the noise certification process.

Normally, when a new type of aircraft is developed, initial noise certification levels are based on the actual noise levels of the aircraft. In other words, initial levels validate present technology. The usual sequence of events is aircraft development first, then creation of a new certification regulation if necessary. In the case of AVF aircraft, such as a civil tiltrotor, the FAA hopes to shave several years off of this regulatory cycle time by developing a noise certification rule (which could be a modification/combination of existing rules or

an entirely new rule) concurrently with development of the aircraft.

If this is to be possible, noise certification rules and procedures for AVF aircraft soon to be under development need to be established as soon as possible. Besides cost and time savings for the government and industry, another advantage of this scenario would be that manufacturers will know what standards new AVF aircraft designs have to meet so they can design to those standards, reducing the risk that new designs won't meet certification requirements. This assures manufacturers that they will be able to bring their new products to market, and thereby recoup their investment, in a timely manner. Such an assurance will probably be necessary before manufacturers commit significant R&D funds for AVF aircraft development.

Acoustic data on AVF aircraft are needed in order to perform an evaluation of what standards are to be applied to first generation AVF aircraft for noise certification. Eventually what is needed is a noise database spanning the full flight envelope of AVF aircraft including revolutions per minute (rpm), speed, approach angles (3-15 degrees), torque, nacelle/wing tilt, etc., before rule and procedure development can be completed. The first certification requirements for AVF aircraft will probably be based on V-22 noise data, just as the first generation CTR will probably be a derivative of the V-22 as it exists today. However, a more comprehensive acoustic database is needed to support manufacturers in the design of future generations of quieter, more acceptable AVF aircraft.

While AVF aircraft will fly the en route portion of flight like a fixed-wing turboprop aircraft, their unique capabilities will encourage the use of innovative flight paths and procedures. AVF aircraft takeoffs and landings are likely to use steeper ascent and descent angles in instrument conditions than those currently certified for fixed-wing aircraft and helicopters.

In light of the complexities associated with AVF aircraft, noise certification procedures should be based on both existing helicopter and fixed-wing procedures to provide commonality, where appropriate, with current requirements. The International Coordinating Council of the Aerospace Industries Association (ICCAIA) has reviewed the development of noise certification schemes for tiltrotor and tiltwing aircraft using data from the United States and Europe. This review established that in addition to takeoffs and landings like a helicopter, short takeoff and landing (STOL) operations may be used by such vehicles. The following quotes from the second meeting of the ICAO Committee on Aviation Environmental Protection (CAEP) held in Montreal, 2-3 December 1991 provide a discussion of noise-related aircraft type certification issues, by flight phase, and

represent the evolution of existing standards to cover a new technology (reference 10).

VTOL OPERATIONS - "During the takeoff and landing, tiltrotor aircraft will operate as a helicopter and thus in general terms the current helicopter rules/limits (chapter 8/appendix 4) would appear to be a sensible starting point. For the flyover, however, where the tiltrotor operates like a fixed-wing (propeller) aircraft, chapter 3/appendix 2 rules/limits would seem appropriate."

TAKEOFF - "A generalized procedure similar to chapter 8 for helicopters will need to be considered. The same noise limits as listed in chapter 8 could be adopted assuming that the tiltrotor will maintain a helicopter configuration during the 10-dB down points."

APPROACH - "It is assumed that the tiltrotor will be able to operate in the approach mode like a helicopter. Such aircraft will, however, typically fly approaches very different from those used by helicopters. Therefore, to ensure that no artificial constraints are imposed on such vehicles, it is proposed that any profile within the safety constraints set by the flight manual will be flown. Then in order to provide a reference procedure, the noise data will be corrected back to an equivalent fixed altitude of 120 meters (corresponding to current chapter 8 reference approach) or a higher value, say 200 meters, to account for steeper approaches envisaged for such aircraft. The chapter 8 limits could then be applied."

FLYOVER - "Since the tiltrotor can operate like a fixed-wing aircraft in the flyover mode, it may seem logical to apply heavy-prop aircraft procedures. This, however, is considered not very appropriate and it would seem more reasonable to adopt a constant speed-fixed altitude flyover. It would appear that an altitude in the range of 300 meters is reasonable for vehicles of the size currently being developed.

It is considered that chapter 8 flyover noise limits would be higher than the noise generated by tiltrotor and tiltwing aircraft and, hence, seem not justified. It would be more appropriate to convert the heavy-prop/chapter 3 flyover noise limit to an equivalent limit at a 300-meter altitude.

In order to maintain uniformity throughout the three noise conditions, it would be necessary to specify a 3-microphone array for the flyover mode." The altitude for the overflight test may have to be altered for different weight classes of AVF aircraft. Higher altitudes would have to be used for AVF aircraft larger than 12,500 pounds, because at low altitudes they would fly so close to the microphones that the noise would rise and fall very quickly and the time between 10-dB down points would be very

short. Lower altitudes would be used for AVF aircraft less than 12,500 pounds, because in the airplane mode and at high altitude the sound measured at the microphone might not get much above ambient noise. This would make the 20-dB noise difference required by the test difficult to achieve.

STOL OPERATIONS - "To cover STOL operations, a procedure along the lines of ICAO annex 6 attachment B is envisaged, but this has not been studied in any depth by ICCAIA."

Current helicopter noise certification testing methodology defines precise engine power settings and flight paths (approach, departure, and overflight paths) with little margin for error allowed. However, the prescribed glideslope for approach is designed to take the helicopter through the noisiest part of its flight regime. It remains to be seen whether the same methodology will be applied to AVF aircraft or whether different models of AVF aircraft will be allowed to fly unique, optimized combinations of engine power setting, nacelle/wing tilt, and flight profile (such as steep angle, decelerating approaches) that result in the lowest noise footprint possible for each individual aircraft.

Current noise certification regulations do not consider the flexibility of vertical flight aircraft as a means of minimizing noise during approach and departure. This strict methodology does not reflect the way rotorcraft operate on a day-to-day basis. It imposes approximately a 6-dB penalty on rotorcraft operations, which may be enough to prevent AVF aircraft from being certified. The question is whether or not the FAA will allow AVF aircraft manufacturers to define low noise procedures for their aircraft. This may require review and approval of separate flight profiles for each aircraft type when certification test plans are submitted for approval. Other issues that need to be addressed in developing certification procedures for AVF aircraft include margins of error that will be allowed from defined parameters once they are established and whether data adjustments with their added complexity will be required (this issue is discussed in the next section).

4.3.2 Simplified Noise Certification Procedures

The primary noise-related concern of helicopter manufacturers today is the high cost of certificating new helicopter models, or an acoustically changed model of an already certificated model, for compliance with 14 CFR 36-H. An applicant for helicopter noise certification must undergo more rigorous testing than a fixed-wing applicant. This is especially true for after-market modification vendors seeking supplemental type certificates (STC) for their products. It is feared by some after-market manufacturers that certification costs may be detrimental to the

after-market modifications industry if full noise certification is required for every change in airframes and engines.

The current regulation requires a page in the aircraft's flight manual for all Stage 2 helicopters stating the noise levels measured during 14 CFR 36-H flight testing. Additionally, for each kit configuration installed under an STC, noise levels must also be provided as a supplement in the performance section of the manual.

The FAA's responsibility and incurred costs are also extensive. In addition to being required to witness the testing itself, the approval process, from endorsement of the initial test plan to validation of test software and hardware, is cumbersome.

Manufacturers' actual experience with noise certification substantiates a cost of between \$200,000 and \$450,000 per type certification or STC. As discussed above, initial certification requirements for AVF aircraft will probably be similar to existing fixed-wing and helicopter requirements. Therefore, it could be assumed that AVF aircraft certification costs will probably be similar also.

One of the major contributors to the high cost of noise certification is the rigidity of the procedures. The helicopter must fly strictly defined approach, overflight, and departure profiles. There is little margin allowed for deviation, either in the horizontal track or glideslope, from these defined flight paths. Many test runs are invalidated, because the pilot cannot hold the helicopter close enough to the prescribed flight path. In addition, the test window mandated by weather requirements (temperature, humidity, wind, etc.) is restrictive. Manufacturers report having to cancel many days of testing because of weather conditions outside of the approved test window.

Another major contributor to high noise certification costs is the complexity of the data correction procedures which must be applied to collected noise measurements. Corrections for deviation from the assigned flight path, humidity, wind speed, and specific tones must be applied every half second for every one-third octave from 50 through 10,000 Hertz (Hz). This results in a major data reduction effort. Industry feels that serious consideration needs to be given to developing "no adjustment windows" in which no data corrections would be required for a specific range of atmospheric conditions and slight deviations from prescribed flight paths.

The stringency of 14 CFR 36-H is acceptable to industry; the complexity, time, and cost burden are not. Industry feels that other methods, such as analysis, modeling, and demonstration, need to be developed in order to reduce the cost of noise

certification, especially for derivatives of models that have already been certified. For example, in September 1992 the FAA issued a rule adding a new appendix (appendix J) to the noise regulations. This noise certification procedure allows a new, simplified screening method to be applied to light (less than 6,000 pounds) primary, normal, transport, and restricted category helicopters as an alternative to full noise testing. Adoption of appendix J is intended to provide regulatory relief to manufacturers of light helicopters by substantially reducing the costs of demonstrating compliance with noise regulations. Originally, this screening method was only for piston-engine rotorcraft. However, it has been expanded to cover turbine-engine rotorcraft also.

The simplified test requirements are 2 dB more stringent but less expensive to perform than the testing prescribed in appendix H. Manufacturers may still use the original procedures if they fail to meet the simplified noise requirements. However, by using the new procedures, the costs of noise certification testing may be reduced by 90 percent. Industry is hopeful that this type of innovative relief from expensive flight testing may also be utilized in the future for at least some aspects of AVF aircraft noise certification as results of current R&D efforts become available. The FAA has recommended to CAEP that ICAO adopt the same screening method. The new ICAO standard is expected to be adopted formally in November 1993.

4.3.3 FAA/ICAO Harmonization

Another factor that increases certification costs for vertical flight aircraft manufacturers is the differing noise certification requirements of various nations, as contained in ICAO annex 16, chapter 8 and 14 CFR 36, appendix H. These differences require manufacturers that sell aircraft throughout the world to satisfy more than one noise standard to gain approval to sell their product. This results in added certification costs and elevated business costs for the civil rotorcraft industry. Harmonized regulations that contain the same technical requirements everywhere in the world, such as the new rule for helicopters less than 6,000 pounds discussed in section 4.3.2, will benefit the entire vertical flight industry. In addition, standardized interpretation and application of the regulations is essential to achieve true harmony.

4.3.4 Metrics

Regulatory issues of importance in the area of metrics pertain to measurements of noise levels for certification purposes (14 CFR 36) and measurements of community acceptance for noise compatibility planning (14 CFR 150).

4.3.4.1 Noise Certification

There is some concern in the industry that current noise models do not adequately address community acceptance criteria and that a proper measure of AVF aircraft noise with respect to community impact and acceptance is needed before the FAA can develop certification requirements for AVF aircraft. However, this second concern may be misleading, since Part 36 of the FARs is not intended to address that issue and does not consider community impact and acceptance criteria in its noise certification requirements.

The philosophy and intent guiding the FAA's noise certification requirements are summarized in the preamble to the original issuance of Part 36 as follows: "Compliance with Part 36 is not to be construed as a federal determination that the aircraft is 'acceptable,' from a noise standpoint, in particular airport environments. Responsibility for determining the permissible noise levels for aircraft using an airport remains with the proprietor of the airport. The noise limits specified in Part 36 are the technologically practicable and economically reasonable limits of aircraft noise reduction technology at the time of type certification and are not intended to substitute federally determined noise levels for those more restrictive limits determined to be necessary by individual airport proprietors in response to the locally determined desire for quiet and the locally determined need for the benefits of air commerce. This limitation on the scope of Part 36 is required for consistency with the responsibilities placed upon the airport proprietor by the United States Supreme Court in Griggs v. Allegheny County, 369 U.S. 84 (1962). Consistent with this limited scope, this amendment specifies that the Federal Aviation Administration makes no determination, under Part 36, on the acceptability of the prescribed noise levels in any specific airport environment." This limitation is also directly codified in §36.5 of Part 36, which states: "Pursuant to 49 U.S.C. 1431(b)(4), the noise levels in this part have been determined to be as low as is economically reasonable, technologically practicable, and appropriate to the type of aircraft to which they apply. No determination is made, under this part, that these noise levels are or should be acceptable or unacceptable for operation at, into, or out of any airport."

There are also assumptions within industry that first generation AVF aircraft will have to comply with existing stage 2 helicopter criteria, while succeeding generations of AVF aircraft will be subject to more stringent criteria. Tests have shown that V-22 and XV-15 noise levels fall at or below stage 2 helicopter noise standards. This does not necessarily mean that these aircraft have acceptably low noise levels. Helicopter stage 2 standards are based on 20-year old technology. Until more acoustical data is available, a determination on whether AVF aircraft will be

certificated to existing or new standards cannot easily be answered.

Another issue is whether current noise metrics that were developed for fan jets (i.e., A-weighting and effective perceived noise level (EPNL)) and de-emphasize low frequency noise are applicable to AVF aircraft. The frequency weightings used in A-weighting may not be meaningful at low frequencies (11 to 20 Hz), the range in which AVF aircraft will be producing noise. The low frequency noise produced by AVF aircraft is distinct and easily recognizable. In addition, it may cause structural vibrations in buildings near a vertiport, especially on approach. If this is the case, noise from AVF aircraft will be more noticeable, and therefore potentially more annoying, than other aircraft noise.

On the other hand, there is research that indicates A-weighting is an adequate measure of AVF aircraft noise. CERL has found that while impulsive sounds such as gunfire and blast noise are "special" and require special penalties or adjustments, helicopter sound is adequately addressed using standard A-weighting methods.

Until agreement on an acceptable metric is achieved, many experts believe more research in this area is required. They feel a universally accepted and consistent methodology for noise assessment needs to be developed. Hopefully, additional research on noise metrics will more clearly define human perception of noise and the variables affecting human response to noise. However, it appears that the empirically developed metrics in use today are a valid starting point.

4.3.4.2 Community Acceptance

There has been some concern in the industry that there may be a need to re-examine the standardized metric currently used for measuring community acceptance, day-night sound level (DNL, or L_{DN}). For assessing long-term exposure, the yearly average DNL is the specified metric used in the 14 CFR 150 noise compatibility planning process. This is in contrast to two single-event cumulative energy metrics used for other purposes: sound exposure level (SEL) and EPNL.

Although DNL has been designated by the FAA as the proper measure of community annoyance, its use has been questioned as not truly representative of public annoyance. Some experts feel that the 14 CFR 150 process should require single-event noise levels, peak hour noise levels, and/or low frequency noise levels. There are questions on whether an average cumulative energy metric such as DNL, which is used in the analysis of noise from conventional aircraft, is appropriate for analysis of vertical flight aircraft noise. Most commercial airports have hundreds of operations a day, while heliports generally handle fewer than 30. The metric

used to analyze helicopter noise should be sensitive enough to accurately reflect community response at comparatively low levels of noise exposure.

In the case of low frequency noise, sound frequencies below 500 Hz exist up to 6 miles behind departing aircraft (reference 11); without a single-event noise standard and with the use of a weighing scale using the DNL metric, some groups and individuals affected by vertical flight aircraft noise feel there is a failure to identify this problem which impacts the community.

Various scales (for evaluation of annoyance for single events) and indices (for evaluation of community annoyance for multiple events over some unit of time) are used to evaluate and compare the annoyance effect of aircraft noise. These scales and indices attempt to account for observer reaction to aircraft noise and to correlate observer annoyance with community annoyance. An aircraft noise scale should include the effects of sound pressure level, frequency spectra (including the presence of pure tones), duration, and spatial distribution of the noise source. An aircraft noise index should also include the effects of number of occurrences and time of day of the noise exposure. In addition to physical characteristics of noise exposure, subjective response and cognitive meaning should be accounted for using a valid scale or index of aircraft noise exposure. These factors are integral in selecting an appropriate metric to measure community noise exposure.

Much of the criticism of the use of DNL for community annoyance and land use compatibility around airports stems from a failure to understand the basis for the measurement or calculation of that metric. This misunderstanding may arise from the fact that although DNL is strongly influenced by the maximum sound level, it is much lower in value and therefore may not convey to the public the loudness of individual flyovers.

In 1990, the Federal Interagency Committee on Noise (FICON) was formed to review Federal policies that govern the assessment of airport noise impacts. The technical subgroup of that committee focused extensively on the question of the applicability of the DNL metric. After reviewing all noise exposure metrics, they concluded that no other metrics are of sufficient scientific standing to replace DNL.

FICON also concluded that supplemental noise evaluation methodologies and metrics, such as single event prediction methods, could be used to provide additional information but had limited application to land use planning. Generally, supplemental metrics are used to further analyze specific noise-sensitive situations. Because of the diversity of such situations, FICON recommended that the use of supplemental

metrics should continue to be left to the discretion of individual agencies.

In the FICON technical report (reference 12), the Committee stated, "The available evidence indicates that DNL continues to be the superior metric to account for variations in the noise environment, including such factors as numbers of flights, loudness of individual aircraft, and percentage of night flights." The Committee's recommendation was to "continue use of the DNL metric as the principal means for describing long-term noise exposure for civil and military aircraft operations." However, they also considered the problem of public understanding of the DNL methodology as substantive and concluded that better explanations should be provided to improve the public's understanding of aviation noise assessment.

It should be noted that the FICON report findings and recommendations largely apply to airports dominated by fixed-wing aircraft. Given the unique noise signatures attributable to vertical flight aircraft and the resulting community response, FICON recommended that future Federal interagency deliberations and analysis include discussions and research on the specific impacts of vertical flight operations.

4.3.5 Simulation Tools

Several computer models are currently being used by the FAA to study human response to noise and the effects of noise on the surrounding land uses and environment.

4.3.5.1 Heliport Noise Model

The Heliport Noise Model (HNM) is the FAA's noise model that uses DNL to generate noise contours for determining Part 150 noise compatibility compliance at free-standing heliports. Although compliance is voluntary, the FAA requires that public-use heliports/vertiports that utilize government funding conduct a noise impact assessment using the HNM or an equivalent. The HNM in its current configuration produces contours for several types of helicopters. Expanding the database to include more helicopters and AVF aircraft is planned by the FAA.

The HNM as currently designed cannot accommodate AVF aircraft. It has only one data set for approach; this data set is used for every segment defined. Therefore, noise differences in transition from fixed-wing to rotary-wing flight caused by different combinations of airspeed, nacelle/wing angle, and descent rate cannot be modeled with the HNM in its current configuration. Most of the HNM's database was compiled from performance tests (noise-power-distance curves) on eight helicopters in 1985. In the future, the HNM will require

operational data on AVF aircraft, such as approach angles, headings, etc., to produce DNL contours.

Objectives for upgrading the HNM include: 1) stabilization of code, 2) incorporation of more helicopter types, and 3) upgrade of the database to include AVF aircraft over the long term. In a related effort, the Air Force has developed and maintains noise contour generator programs for military aircraft similar to the HNM, called NOISEMAP and ROUTEMAP. These noise exposure models may be relevant for use in the HNM upgrade.

Computer noise modeling codes continue to be upgraded. Computer models provide the FAA and industry with innovative tools for determining aviation-related environmental impacts. Flight test data accumulation is ongoing for use in the HNM and the Interactive Sound Information System (ISIS), discussed in the next section. This work is important for both 14 CFR 36 and 14 CFR 150 modifications. Unfortunately, AVF aircraft development may still be years away. After acoustic data on AVF aircraft is available for an HNM upgrade, there is a development cycle of approximately 2 years. Once the HNM is able to generate AVF noise contours, the FAA can evaluate what impact AVF aircraft will have on current Part 150 standards in terms of necessary modifications and begin to apply those standards to vertiports.

BHTI has developed a methodology for predicting the noise footprints for various weight classes of civil tiltrotors by extrapolating from existing XV-15 and V-22 noise databases. However, a more advanced noise database is required to validate this model and to support computer analysis, simulation, and prediction applicable to satisfying certification requirements. Noise prediction methodologies need to accurately model each noise source in order to predict total system noise. An extensive aeroacoustics database will be needed for this. The benefits that could be obtained from this database are many. First, it could be used to answer questions about noise-generating mechanisms and about the effectiveness of noise reduction techniques. Second, it could be used to generate more accurate empirical methods for prediction. Finally, it could be used to validate noise simulations and computer models.

Just as computer-aided design and manufacturing (CAD/CAM) allows aircraft designers to model and closely approximate the final aircraft design before ever cutting metal, noise models of the future could allow designers to closely approximate the final acoustic signature of an AVF aircraft before it is built. This development could have potential for streamlining noise flight testing and certification costs. The FAA's airworthiness officials currently work with aircraft manufacturers to stay abreast of CAD/CAM tools used to develop the aircraft they are responsible for certifying. The same type of joint effort between the FAA and industry will be needed if the next

generation of noise models are to play a role in noise certification.

4.3.5.2 Interactive Sound Information System

The Interactive Sound Information System (ISIS) is a planning tool developed by David Dubbink Associates with the FAA for demonstrating airport noise to developers, planners, and the public under a variety of conditions. It can account for such variables as type and fleet mix of aircraft, location of flight tracks, scheduling alternatives, and soundproofing of buildings. Because the system is interactive, a presenter can change the direction and content of a program to meet audience needs and can even use the system to respond to "what if" questions from listeners as they occur during a presentation. The FAA is using ISIS to assist in its land use compatibility planning efforts at airports. Currently, however, this model contains only digital quality recordings of fixed-wing aircraft.

ISIS has potential application for conducting studies on human response to noise impacts at vertiports, but the program must be upgraded to include vertical flight aircraft and to take into account the confined nature of the vertiport environment. ISIS could be used to develop basic information on community acceptance of vertiports by simulating the impact of vertical flight aircraft operations on the community. These human response studies would allow planners to gain insight into human annoyance as a function of vertical flight aircraft proximity and operating configurations (approach angle, etc.). An upgraded ISIS could be well-suited for the human response studies needed to better understand annoyance factors of AVF aircraft and helicopter noise. Modeling tools such as this can also be used to analyze human response to noise in order to better understand and evaluate the adequacy of current noise metrics.

4.3.6 Vertiport Noise Compatibility Planning

The noise compatibility planning program specified in 14 CFR 150 is a voluntary process for bringing together all elements of the local aviation community to develop consensus noise control and land use actions. By statute, not less than 12.5 percent of the funds appropriated annually for the Airport Improvement Program shall be used for noise compatibility programs. In addition, the FAA requires that new public-use heliports that use government funding conduct a noise impact assessment using the HNM or an equivalent. Thus, eligibility for government funding provides a powerful incentive for voluntary compliance with this regulation. The probability of obtaining government funding for a location that does not meet 14 CFR 150 guidelines is very low.

The Part 150 process currently consists of two phases - the development of a set of noise exposure maps (NEM) to identify

existing and forecasted land use incompatibilities around the heliport, and a Noise Compatibility Program (NCP) to minimize and/or eliminate those incompatibilities. The rule is currently under revision, and it may combine these two steps.

The process is important because it brings together all parties involved in noise issues at an airport or heliport to work out problems at the local level. Experience has shown that aviation noise problems are essentially local in nature, and are best worked out locally. Through court decisions and Federal policy, the airport and/or heliport proprietor is held responsible for any noise damages which might result from operation of the facility. Thus, even without the incentive of gaining Federal funding by carrying out an approved Part 150 program, the very process of developing that program is valuable for addressing local concerns.

If the envisioned contribution of vertical flight aircraft to NAS capacity enhancement is ever to become a reality, application of 14 CFR 150 must be expanded to include vertiports. The RMP calls for development of a nationwide system of vertiports. However, for vertical flight aircraft, at present 14 CFR 150 can only be applied to free-standing heliports due to HNM limitations and a lack of available noise data for AVF aircraft.

Adaptation of 14 CFR 150 to vertiports will require a basic understanding of the vertiport environment in which AVF aircraft will operate, including projected vertiport physical data and typical noise abatement flight profiles to be used at vertiports. This operational understanding can also be used by the FAA to support development/modification of Part 36 noise regulations and certification procedures. Noise impact studies and simulations will be required to determine the noise sensitivity of different land uses surrounding a vertiport and the effects of airspace requirements, approach/departure profiles, aircraft size, and frequency of operation. The HNM and ISIS will be of use in this area.

Although vertiport siting analysis is not directly related to noise compatibility planning, noise impacts must be known so that the effects of various vertiport configurations on the surrounding community can be assessed. This will become more important in the future as analyses for environmental documentation become increasingly sophisticated. Improved tools for conducting heliport siting studies will be needed. For example, there will be a need for geographical information systems (GIS) to predict both source-based and observer-based noise impacts of AVF aircraft.

GIS integrate multiple urban/transportation planning tools into compatible map overlays. It is a technology for the collection, management, and analysis of spatial data which can be used to

geographically depict information for site planning, and analysis of heliports/vertiports and related routings. By combining U.S. Bureau of Census and U.S. Geological Survey topologically integrated geographic encoding and referencing (TIGER) files, census data dealing with population and housing characteristics, etc., can be applied to a mapping overlay system for analyzing heliport/vertiport plans and their alternatives. In addition, GIS can incorporate and show the interrelationships between noise contours, approach/departure profiles, hazards and obstacles, types and densities of land-use patterns, assessed valuation of property, housing conditions, and noise complaint data. GIS will help predict the detectability, audibility, and annoyance of AVF aircraft noise at heliports and vertiports.

4.4 COMMUNITY ACCEPTANCE

Noise is a dominant "social cost" of locating a heliport/vertiport in a community. Although a helicopter may pass noise certification requirements, this provides no assurance that specific operations flown by that helicopter will meet with community acceptance. There are no detailed guidelines for heliport/vertiport and community planners on how to address different noise issues or assess how a community will react to noise. In addition, since measurement of the effect of noise at a given heliport/vertiport can be very subjective, many different conclusions have been reached with regard to a suitable measure of noise disturbance.

While concerns about en route noise may be managed by selection of flight path and altitude, a vertiport site must be located near the population it serves (typically in highly populated areas which are likely to be sensitive to noise). This limits the available means of reducing noise effects on approach and departure to flight trajectory management and use of noise abatement procedures, or using quieter aircraft.

Some community acceptance issues are intangible. Initial research by AHS revealed that public fear of "invasion of privacy" is significant and may be a factor in noise intolerance. The population may not understand the benefits of AVF aircraft to them personally nor the benefits of air commerce to their community. Community education programs are needed to provide the public with an appreciation of what a vertiport can, or will, do to improve their quality of life.

If vertical flight aircraft are to be considered an economically viable alternative to other transportation modes, they will most likely need to operate into highly populated, space-restricted areas, such as city-center vertiports. Multiple GIS overlays, as discussed in section 4.3.6, will facilitate site planning for noise compatibility. However, valid methods of assessing community reaction to noise need to be developed in order to

determine how to balance the operational needs of a vertiport with the needs of the surrounding community.

The following quote from an address before the American Institute of Planning by the Department of Transportation's Acting Assistant Secretary for Environment and Urban Systems addresses the issue of articulating and meeting the needs of the community: "If community goals are to be reflected in transportation planning and the transportation planning process, they must first be articulated. Setting of community goals is the point at which the comprehensive planning process begins....Unfortunately, in most cities, such a statement of goals has not been set--this is an essential first step" (reference 13). This appraisal is true of many metropolitan areas in the United States, especially in the area of vertical flight infrastructure. In other words, the community must be educated to understand the value of heliports/vertiports before such facilities can be included in balanced, comprehensive transportation planning. Before a community will favor a vertiport, it must understand the value of air commerce in general and where vertical flight fits into that picture.

As discussed in section 4.1, annoying sources of noise on helicopters, such as blade slap and tail rotor whine, are being "designed out." Current research into development of rotor blades with improved lifting capability at lower rpms and use of active control techniques may lead to further gains. However, there will probably never be an economically viable, "quiet" vertical flight aircraft. Therefore, more research and development into community acceptance of these aircraft is essential. The issues of importance in this area are discussed in the following paragraphs.

4.4.1 Simulation Tools

Computer models such as ISIS and GIS could be valuable tools for predicting community noise impact if they were adapted for use with vertical flight aircraft, or in the case of the HNM, AVF aircraft. Such models could be used to conduct system studies of noise impacts at proposed and existing vertiports.

Currently, the HNM contains no noise data for AVF aircraft such as tiltrotors. Consequently, noise contours cannot now be drawn for a potential facility to serve such aircraft. ISIS contains no noise data for vertical flight aircraft at all. If such data were incorporated, this would be a powerful tool for exploring the effectiveness of noise abatement strategies for vertical flight aircraft through use of comparative acoustic examples.

4.4.2 Community Acceptance Noise Metrics

As discussed in section 4.3.4.2, the use of DNL as the primary environmental noise descriptor for land use compatibility planning has been questioned as not truly representative of public annoyance. Some experts feel that the 14 CFR 150 process should require single-event noise levels, peak hour noise levels, and/or low frequency noise levels. However, FICON recently re-examined this issue and concluded in their 1992 report that DNL should continue to be used as the primary metric for aircraft noise exposure.

4.4.3 Operational Measures

Pilots need to fully understand noise abatement techniques that are most effective for the type of vertical flight aircraft they fly. Industry initiatives, such as the Helicopter Association International's (HAI) Fly Neighborly Program, have been effective to some degree in dealing with helicopter noise-related problems in some areas. The Fly Neighborly Program focuses on providing immediate environmental benefits to the community through courteous flight operations. In addition, education programs are presented to the community to inform them of the heliport's value to the community and operator efforts to reduce noise. Particular emphasis is placed on:

- o meeting with transportation and urban planners to find compatible heliport sites;
- o coordination with operators to develop discreet flight routes, approaches, and procedures for minimum sound exposure;
- o coordination with helicopter manufacturers to acquire noise data and develop noise abatement piloting techniques for individual helicopter types; and
- o developing a process for community input and issue resolution.

As an example of a comprehensive and particularly effective Fly Neighborly Program, the Hawaii Helicopter Operators Association (HHOA) has a well-developed policy, described in their Fly Neighborly Program Manual (reference 14). Over the past several years, HHOA has been working on noise/nuisance issues for helicopter sightseeing operations in Hawaii. In the past 2 years, they have made significant progress in the implementation of a mandatory noise/nuisance control program for tour operators. The elements of the program are:

- o a hot-line number for residents to call with complaints;
- o a procedure for handling complaints based on photographs of potentially offending helicopters by both the complainers and HHOA officials;

- a set of written procedures (virtually a contract) agreed upon by helicopter operators, helicopter pilots, community representatives, and officials at several levels of government;
- provisions for fines and/or disciplinary actions against offending operators and pilots; and
- identification of areas where helicopters will stay a specified distance (1,500 feet in sensitive areas or 3,000 feet in especially sensitive areas like cemeteries) from noise sensitive areas (includes sightseeing attractions, residences, and other areas where helicopters could intrude on the public).

In addition, participating operators have pledged to continue voluntary noise abatement programs where necessary. Because they are voluntary and can be localized, such programs can often be more stringent than a statewide, mandatory program.

Established helicopter route structures, particularly those requiring low altitudes to avoid fixed-wing traffic in urban areas, tend to concentrate rotorcraft noise impact in specific areas. To preclude this, noise abatement procedures need to be developed on a local level and universally used by the industry. Land uses near a vertiport will determine optimum noise abatement profiles for that location.

4.4.4 Community Education

Vertical flight aircraft suffer somewhat from negative public opinion. Citizen complaints about rotorcraft noise often mask a real or perceived fear of helicopters due to a lack of understanding of their technology and safety. Invasion of privacy, intrusion into "personal space," and feelings that helicopters are only for the rich are other motivations for public concern and opposition.

In other instances, rotorcraft may be perceived to be noisy, not because of the amount of noise they produce, but because of the unique nature of that noise. Again, this is the result of a lack of understanding on the part of the public. Industry and the FAA need to educate the community about the features of vertical flight aircraft so the public can understand what they sound like. In many cases, prior exposure to older, noisier helicopters is causing unfounded concern.

4.4.5 Vertiport Noise Compatibility Planning

The primary issue is to develop a means of balancing the operational needs of a vertiport with the various physical and psychological needs of the community. The noise compatibility planning process spelled out in 14 CFR 150 would be extremely beneficial for application to vertiports. The existing regulation

may be applied to free-standing heliports using the HNM to develop noise contours. However, since the HNM does not currently contain noise data for AVF aircraft, noise contours surrounding facilities where such aircraft would operate are not yet available.

Thorough use should be made of the principles of urban planning for noise control. Efforts should be pursued to obtain public support for vertical flight operations by working with the community, for example, designing an ordinance that gives the community a means of control. If the community feels helpless, they become restrictive. If the community knows it has a say in facility planning and noise control programs, it is much more likely to cooperate in the development of new heliports and vertiports.

Land use and noise compatibility planning must be emphasized, because the noise generated by vertical flight aircraft will affect infrastructure design and location in the long run. For instance, the number, location, and size of heliports may be affected by TERPS requirements, such as protected airspace requirements for approaches and departures. Nonprecision approaches require more protected airspace than precision approaches. Similarly, protected airspace requirements are also a consideration at a visual flight rules (VFR)-only heliport. The greater the amount of protected airspace required, the greater the restrictions on development of property adjacent to a facility. These restrictions may lessen noise sensitivity on the adjacent property, but if the property is not owned by the facility and cannot be purchased, the location may ultimately become unacceptable. In any case, the relationship between acceptable noise levels and restrictions placed on development by protected airspace requirements needs to be considered.

The load capacity and size of vertical flight aircraft anticipated at a given location will affect size of the noise footprint, vertiport design, location, and groundside sizing. Since few heliports are now located in commercial business districts, there is little operational experience to guide the FAA and rotorcraft operators in developing siting criteria for new vertiports. Siting guidelines that take into account land use and noise compatibility issues would promote acceptance of vertical flight operations at vertiport sites where the community could be significantly affected by noise.

5.0 NEAR-TERM REQUIREMENTS

Section 4.0 defined the scope of the noise problems facing the vertical flight community. This section identifies requirements that must be met, i.e., projects and efforts that must be undertaken, to resolve the issues defined earlier. For purposes of this plan, near-term requirements are defined as efforts targeted for accomplishment in the 1993 to 1996 timeframe. A summary of requirements for the four major plan areas is depicted in figure 1.

5.1 TECHNICAL

R&D requirements leading to a design-for-noise capability are summarized in figure 2.

5.1.1 Database Development

The highest priority requirement for vertical flight noise R&D is to develop a noise database for AVF aircraft. This is a requirement that cuts across all four areas discussed in this plan. Essentially, no noise database of significance exists for a V-22-sized tiltrotor. This information is essential to determine operational procedures and flight profiles to minimize community impact, to develop a new or modified noise certification rule for AVF aircraft, to quantify the acoustic benefits of advanced rotor blade designs, to determine the magnitude of the acoustics challenges for this new category of aircraft, and to support refinement of AVF aircraft noise prediction methodologies.

Flight, model, and wind tunnel tests should be conducted to obtain comprehensive data under a variety of operating conditions. The database from the XV-15/ATB flight test program underway at NASA Ames Research Center should be correlated with analytical methods. In addition, when a database is obtained from the V-22 flight test program, this should be correlated with both the XV-15 database and analytical methods.

5.1.2 Noise Generation

Projects that need to be undertaken to resolve noise generation issues are listed below.

1. Theoretically, experimentally, and computationally evaluate various noise mechanisms of tiltrotor aircraft and rank them by relative importance. In particular, establish the effects of:
   - o different paths of tip vortices in the wake;
   - o higher disk loading;
   - o phasing between signals from two rotors;

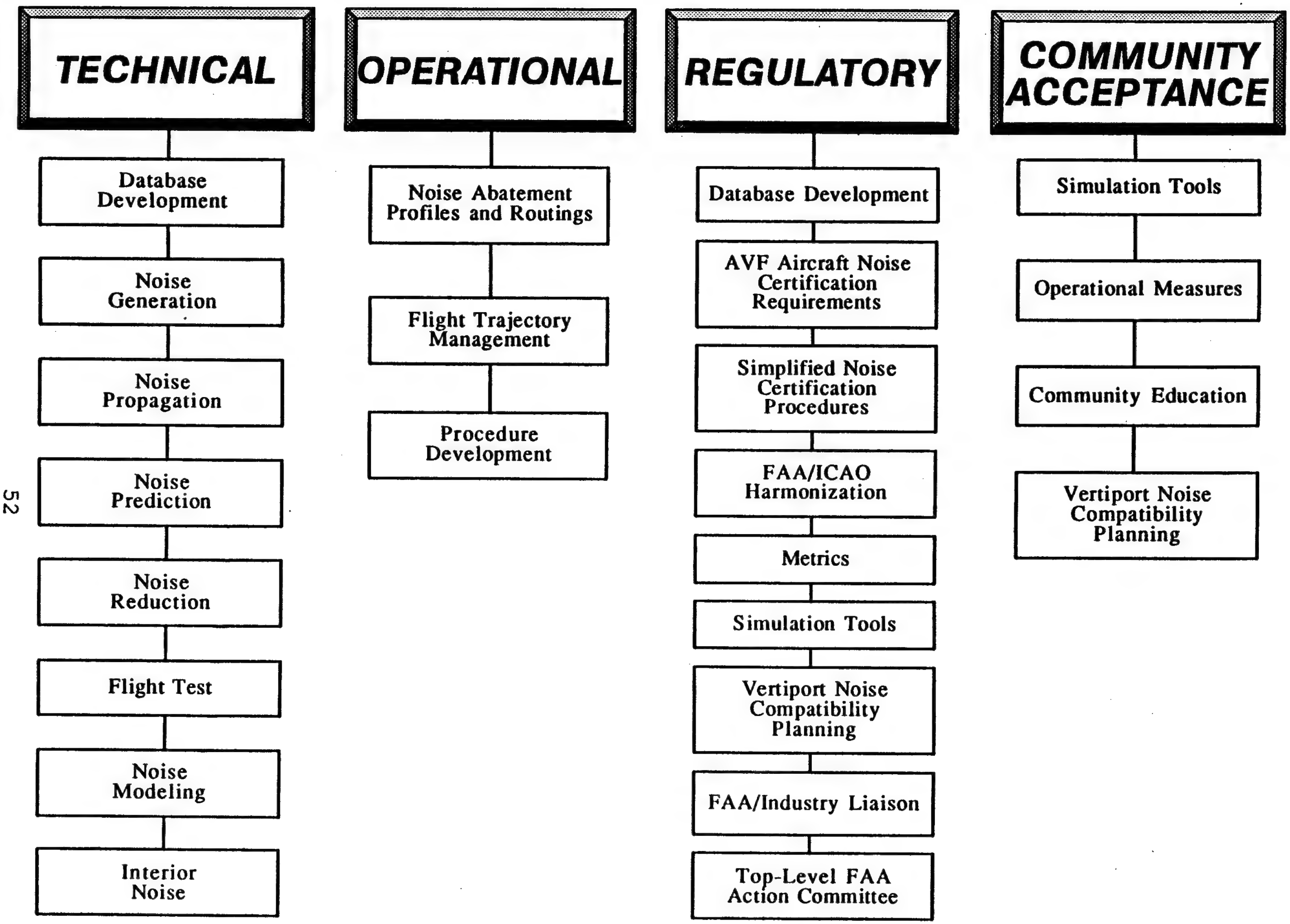


FIGURE 1 VERTICAL FLIGHT NOISE R&D REQUIREMENTS

TECHNICAL R&D REQUIREMENTS

DATABASE DEVELOPMENT

- Conduct flight, model, wind tunnel tests under a range of operating conditions
- Correlate XV-15/ATB database with analytical methods
- Correlate V-22 database with XV-15 database and analytical methods

NOISE GENERATION

- Evaluate and rank various noise mechanisms
- Develop analytical methods to predict vortex size and wake geometry
- Characterize and control fountain flow phenomena
- Conduct wind tunnel study on installation effect of tiltrotor noise
- Study effects of turbulence on rotor noise
- Quantify key parameters affecting vortex breakdown from a rotor

NOISE PROPAGATION

- Assess applicability of current models to AVF aircraft noise
- Develop a code involving the effect of winds, atmospheric attenuation, ground effects, caustics, multipaths, and shadow zones
- Measure atmospheric turbulence and other meteorological parameters in conjunction with sound pressure levels
- Measure long-distance propagation from first generation tiltrotors

NOISE PREDICTION

- Develop a code which couples aerodynamic, source, and propagation models
- Emphasize modularity and consistency between models
- Correlate ROTONET and other helicopter noise codes with vertical flight noise data

NOISE REDUCTION

- Develop and validate active noise control technologies
- Evaluate noise reduction goals for the V-22 through comparisons with acoustic flight test data

FLIGHT TEST

- Continue XV-15/ATB flight test; compare ATB performance with standard blades
- Conduct V-22 flight tests to gather acoustic data and evaluate noise reduction flight procedures
- Pursue UH-60 and other rotor-blade-loads experiments to validate existing and developing systems noise prediction methods

NOISE MODELING

- Develop small-model research capability to examine acoustics and fluid dynamics
- Conduct testing using TRAM in isolated rotor, semi-span rotor/wing, and full-span configurations

INTERIOR NOISE

- Perform detailed measurement and analysis using V-22
- Conduct R&D on low noise blades/tip configurations and on increased spacing between fuselage and proprotor
- Validate airborne and structureborne interior noise prediction models

FIGURE 2 TECHNICAL R&D REQUIREMENTS

- variable orientation of rotors and nacelles with respect to an observer;
- wing-rotor wake interaction;
- blade loading differences due to higher twist; and
- close passage of blade tips to the fuselage in the airplane mode.

2. Develop analytical methods to predict vortex size and wake geometry.

3. Characterize and control fountain flow phenomena through flow and acoustic experiments and analysis.

4. Conduct a systematic anechoic wind tunnel study on the installation effects of tiltrotor noise.

5. Conduct a combined theoretical and experimental study of the effects of turbulence on rotor noise. Objectives for the study should include:

   - improvement of rotor aeroacoustic prediction models for turbulence rotor interaction, including evaluation of real atmospheric effects;
   - experimental measurement of the effects of rotor inflow on both isotropic and non-isotropic turbulence; and
   - flight test measurement of noise radiation from tiltrotor aircraft in carefully characterized turbulent/unsteady flow conditions.

6. Conduct experimental qualification of key parameters affecting vortex breakdown from a rotor, so that predictive models can be offered to aircraft designers.

5.1.3 Noise Propagation

Efforts required to resolve noise propagation issues include the following candidate projects.

1. Assess the applicability of current sound propagation models to AVF aircraft noise.

2. Develop a code that takes into account the effects of winds, atmospheric attenuation, ground effects, caustics, multipaths, and shadow zones.

3. Make extensive measurements of atmospheric turbulence and other meteorological parameters in conjunction with sound pressure levels to validate propagation codes.

4. Measure long-distance propagation from first generation tiltrotor aircraft.

5.1.4 Noise Prediction

The following projects need to be undertaken in the area of noise prediction.

1. Develop a code which couples various aerodynamic, source, and propagation models.

2. Emphasize modularity and consistency between models, especially the ability to incorporate the most advanced models as they become available.

3. Correlate ROTONET and other helicopter noise codes with tiltrotor noise data, and improve ROTONET.

5.1.5 Noise Reduction

To date, making the V-22 a quieter vehicle has not been a priority. It is estimated that a 12-dB noise reduction would be needed to make the V-22 (or some commercial variant of it) acceptable as a CTR. However, this needs to be verified with V-22 acoustic flight test data. Also, the 12-dB reduction would include a 6-dB reduction obtained through use of low noise operating procedures. These goals need to be evaluated through comparisons with V-22 acoustic flight test data.

Aggressive development and validation of active noise control technologies are needed to reduce both interior and far field noise. However, until noise source mechanisms are better understood, an improved noise prediction capability is at hand, and adequate noise reduction methods have been developed, a balanced approach to R&D must be taken that pursues both source noise reduction and operational procedures to minimize the noise impact of tiltrotor aircraft.

5.1.6 Flight Test Program

XV-15/ATB acoustic tests must be continued to further investigate noise mechanisms identified in previous tests, to measure lower hemispherical acoustic characteristics, to evaluate noise reduction flight procedures, and to obtain rotor/airframe airloads data measurements with pressure-instrumented ATB. Comparisons should also be made of ATB and original blade noise characteristics.

A flight test program to evaluate the V-22 against potential certification requirements and to provide data for community noise impact assessments is needed. Critical noise problems in the terminal area environment should be emphasized. It may be unacceptable to extrapolate existing XV-15 data to transport size aircraft. Based on some of the prediction work completed in studies for NASA, a V-22-class CTR transport vehicle will

probably suffer from high noise levels, particularly in a vertiport environment during descent and hover. Some programs using the XV-15 in the near future can address these issues, particularly in validating acoustic methods. However, this vehicle does not possess the sophisticated controls or engine throttling capability necessary to conduct flight maneuvers during descent that may be inherent in some operational noise abatement procedures for AVF aircraft. Several flight tests are necessary using the V-22, and even that vehicle will require modification of the engine controls to allow full evaluation of noise reduction possibilities.

NASA's AT^3 Program, currently in the planning stages, identifies the need for a 12-dB reduction in V-22 class tiltrotor noise. Six dB of this noise reduction has been identified as possible through the use of low noise profiles. In addition to experimental efforts with the XV-15 and V-22, aggressive steps must be taken to develop prediction tools that can be used to conduct trade-off studies for defining variable operating conditions during these low noise profiles. Experimental programs cannot address all possible variables in these profiles, but must be designed to provide selected data in order to anchor these predictions.

In addition to XV-15 and V-22 vehicle utilization, UH-60 and other rotor-blade-loads experiments need to be aggressively pursued as validation tools for existing and developing systems noise prediction methods. The Applied Acoustics Branch at NASA Langley Research Center plans to support flight test activities using the XV-15 or V-22 with highly instrumented rotor blades. Only from carefully controlled flight experiments with precise measurements can the vertical flight industry hope to develop confidence in their prediction capabilities for new and innovative design concepts.

5.1.7 Noise Modeling

Small-model research capability to examine the acoustics and fluid dynamics of tiltrotor aircraft is urgently needed. Presently, large scale validation of noise reduction is required due to uncertainties in scaling laws. Further, flight testing is required for risk reduction, since no wind tunnel capability exists for large-scale, full-span tiltrotor configurations.

Aeroacoustic tests should be conducted using the tiltrotor aeroacoustics model (TRAM) being developed by NASA Ames, NASA Langley, and the U.S. Army AFDD. Currently, tests are planned in several NASA and European wind tunnels in Fiscal Year (FY) 93 through FY 95. The model will be configured for testing as an isolated rotor, semi-span rotor/wing, and as a full-span model. Test results will help to establish design-for-noise capability for next generation tiltrotor aircraft. Caution needs to be

exercised, however, in extrapolating small-scale data to the full scale. Before acquiring detailed parametric data from small-scale models, discrepancies noticed between the full-scale V-22 and models of the V-22 should be resolved (model-scale noise data shows considerably higher harmonic content than full-scale data).

5.1.8 Interior Noise

To thoroughly investigate tiltrotor internal noise characteristics, detailed measurement and analysis should be performed using the V-22. Such improved understanding could provide the basis for further research leading to appropriate soundproofing for a future CTR.

Aggressive development and validation of active suppression systems are needed to reduce interior noise in AVF aircraft. Incorporating these technologies with proven passive methods should produce interiors competitive with other air transportation vehicles. Research and development on low noise blades/tip configurations and on increased spacing between fuselage and proprotor are urgently needed. Validated airborne and structure borne interior noise prediction models must be developed that take into account acoustic loads and structural parameters.

5.2 OPERATIONAL

Operational requirements for vertical flight noise R&D must focus on identification of critical noise problems resulting from vertical flight operations, particularly in the terminal area environment, and assessment of the benefits that may be realized from low noise operational procedures. In addition, crew training guidelines must be developed for using such procedures. Requirements in this area are summarized in figure 3.

5.2.1 Noise Abatement Profiles and Routings

Flight profiles and routings must be developed that incorporate effective noise abatement principles such as the ones listed in section 4.2.1, yet at the same time are acceptable to passengers who would use commercial vertical flight service. Steep approaches and departures, while optimum for noise abatement, may not provide the comfort that paying passengers have come to expect. Such procedures should be evaluated from a public acceptance viewpoint, as well as from a safety and noise impact perspective.

Other potential tasks to be accomplished in this area include identification of low-noise conversion corridors for tiltrotor and tiltwing aircraft under controlled test conditions and

OPERATIONAL R&D REQUIREMENTS

NOISE ABATEMENT PROFILES AND ROUTINGS

- Develop profiles and routings that incorporate noise abatement principles
- Evaluate noise abatement profiles and routings in terms of passenger acceptance
- Identify a low-noise conversion corridor for tiltrotors and tiltwings
- Conduct flight test to evaluate the limits of potential low-noise approach and departure profiles

FLIGHT TRAJECTORY MANAGEMENT

- Continue research to devise flight strategies using optimum combinations of airspeed, nacelle tilt, glideslope angle, altitude, etc., to reduce noise impact of vertical flight aircraft
- Determine minimum noise region in V-22 (or civil derivative) flight envelope
- Conduct research on automatic flight control systems to schedule nacelle angle and airspeed
- Expand CTR Noise Impact Prediction Methodology to include additional flight conditions

PROCEDURE DEVELOPMENT

- Develop environmentally acceptable terminal area procedures for vertical flight aircraft (VERTAPS program)
- Develop a standard noise abatement procedure for use at all vertiports
- Investigate optimum noise/safety/efficiency curves
- Define permissible flight envelopes
- Evaluate the effect of steep approach/departure angles on noise footprint area
- Study feasibility of steep approach angles for commercial CTR operations
- Test strategies and develop guidelines for reducing noise levels on landing and takeoff, and in glideslope and flight corridors

FIGURE 3 OPERATIONAL R&D REQUIREMENTS

operational flight tests to evaluate the limits of potential low noise approach and departure profiles for vertical flight aircraft.

5.2.2 Flight Trajectory Management

The research previously done in this area should be continued and expanded to devise flight strategies using optimum combinations of airspeed, nacelle tilt, glideslope angle, altitude, etc., to reduce the noise impact of vertical flight aircraft on the community and environment. When an aircraft becomes available, studies should be conducted on a tiltrotor comparable in size to the V-22 to determine the regions of minimum, moderate, and maximum noise within the flight envelope (this has already been done with the XV-15). With knowledge of these regions, the transition between helicopter and airplane modes could be planned to take full advantage of the minimum noise region identified. Research should also be conducted on flight control systems that may offer the opportunity to automatically schedule nacelle angle and airspeed for optimum noise abatement.

The CTR Noise Impact Prediction Methodology recently developed by BHTI should be expanded to include additional flight conditions, particularly transition to hover. This requirement again highlights the need for a comprehensive vertical flight aircraft acoustic database, in particular V-22 (or a civil derivative) noise data.

5.2.3 Procedure Development

5.2.3.1 VERTAPS

The VERTAPS program should be pursued in order to develop terminal area procedures to promote integration of vertical flight aircraft into the NAS. To allow evaluation of the noise impact of different flight profiles and procedures, noise models should be incorporated into the simulations to generate a noise footprint for candidate procedures and thus a relative measure of community acceptance. These relative ratings of noise impact will constitute one of the bases for discrimination among potential procedures being considered.

Areas to be defined and evaluated for vertical flight instrument procedures should include:

- obstacle clearance requirements for approaches, missed approaches, and departures;
- operating minima; and
- procedural design criteria for approaches, missed approaches, and departures.

Areas to be defined and evaluated for vertical flight ATC procedures should include:

- approaches and departures,
- transition from en route to terminal phase,
- holding patterns,
- timing and spacing requirements,
- emergency procedures, and
- radar versus nonradar procedures.

5.2.3.2 Noise Abatement Approaches/Departures

The FAA recognizes the need for noise abatement procedures and possibly a standard noise abatement procedure for use at all vertiports. The development of operational procedures for vertical flight aircraft must include investigation of optimum noise/safety/efficiency curves, definition of permissible flight envelopes, and evaluation of the effect of steep approach and departure angles on noise footprint area. These operational studies, along with technological and ATC studies, will promote noise abatement alternatives that in turn will lead to quieter vertical flight operations.

Studies of the feasibility of using steep approach angles for commercial CTR operations should be continued, as well as validation of cockpit control/display concepts for precision control and management of pilot workload under such conditions.

5.3 REGULATORY

Regulatory requirements for vertical flight noise R&D are summarized in figure 4.

5.3.1 Database Development

The FAA is currently performing flight testing of medium and heavy transport helicopters in order to develop an acoustic database that will support simulation and analysis of vertical flight aircraft acoustic properties. This flight test needs to be expanded to include AVF aircraft in order to provide a basis for AVF noise certification regulations and procedures. A method and schedule for obtaining AVF acoustic data needs to be identified; however, collecting this data probably cannot be accomplished in the near term since aircraft are currently unavailable.

In addition to supporting rule development, data collected during acoustic flight testing will be used to develop and improve computer noise models, design noise abatement procedures, and upgrade the existing FAA acoustic database. Stage 3 requirements for vertical flight aircraft will also need to be evaluated as acoustical data is collected.

REGULATORY R&D REQUIREMENTS

DATABASE DEVELOPMENT

- Acquire comprehensive acoustic data on AVF aircraft to support development/modification of certification requirements

AVF AIRCRAFT NOISE CERTIFICATION REQUIREMENTS

- Develop certification requirements (new/modified rule) for AVF aircraft
- Develop generic vertiport physical data
- Define noise abatement flight profiles for certification testing

SIMPLIFIED NOISE CERTIFICATION PROCEDURES

- Reduce complexity and cost of current helicopter certification procedures
- Redefine acoustical changes requiring noise testing
- Develop equivalent procedures
- Expand test windows and reduce complexity of data correction procedures

FAA/ICAO HARMONIZATION

- Work toward international standardization of noise regulations
- Form a task force to coordinate development of domestic and international standards

METRICS

- Evaluate standard metric for noise certification (EPNL)
- Improve public understanding of the DNL metric and supporting methodology
- Establish Federal guidelines for what dB level is acceptable at vertiports
- Develop a method for predicting long-term average noise levels of helicopter operations in and around airfields

SIMULATION TOOLS

- Upgrade HNM to improve stability and to incorporate AVF aircraft data
- Upgrade ISIS to include vertical flight aircraft and vertiport environment
- Investigate feasibility of applying simulation models to noise certification process

VERTIPORT NOISE COMPATIBILITY PLANNING

- Expand application of 14 CFR 150 to vertiports
- Conduct siting analyses using GIS to increase understanding of noise impact around vertiports

FAA/INDUSTRY LIAISON

- Establish an active partnership between FAA and industry to enhance noise R&D that will benefit both parties

TOP-LEVEL FAA ACTION COMMITTEE

- Form a top-level action committee within FAA to plan, enforce, and expedite noise rule development, acoustic data acquisition, computer model upgrades, etc.
- Maintain close coordination between involved FAA offices in order to achieve common goals

FIGURE 4 REGULATORY R&D REQUIREMENTS

5.3.2 AVF Aircraft Noise Certification Requirements

The RMP identifies noise as a critical challenge to successful integration of helicopters and AVF aircraft into the NAS. Development of noise standards well in advance of first generation AVF aircraft is necessary in order to meet that challenge. Noise data from the V-22 will most likely be used to support initial rule development. In addition, generic vertiport physical data should be defined, i.e., what a typical vertiport will be like in terms of size, location, surrounding environment, etc., for use in developing a noise certification rule for AVF aircraft. Advisory Circular 150/5390-3, "Vertiport Design," provides general siting guidance, airside and groundside design standards, and airspace considerations that may be applied to assist in developing this data. Noise abatement flight profiles must be developed for certification testing to take advantage of the unique capabilities of aircraft such as tiltrotors.

Once an AVF aircraft noise database is obtained, the FAA must develop and publish noise certification procedures and requirements in a timely manner so that manufacturers and agencies such as NASA can apply relevant R&D efforts to the design of next generation AVF aircraft. In this way, initial noise certification requirements will enable development of flight test programs to collect more comprehensive acoustic data, which will in turn result in improved designs for next generation, quieter AVF aircraft. Initial noise certification requirements will probably be based on current fixed-wing and helicopter certification requirements. However, if the process is started early enough, more efficient and economically viable methods, such as those discussed in section 4.3.1, may be developed for AVF aircraft noise certification.

Any exceptions to AVF aircraft noise regulations need to be defined early. For example, will the V-22, or a first-generation civil version of it, be grandfathered from more stringent requirements that succeeding generations of AVF aircraft may have to meet? In addition, the effective date for any new noise regulations for AVF aircraft needs to be determined.

5.3.3 Simplified Noise Certification Procedures

Existing noise certification procedures for helicopters should be simplified to reduce the complexity and cost of testing for vertical flight aircraft manufacturers. Steps to accomplish this could include:

- o mandating less restrictive test windows (weather requirements) for certification testing and developing "no adjustment windows" in which no data corrections would be required for a specific range of atmospheric

conditions and slight deviations from prescribed flight paths;

- making acoustical change provisions less rigid and more realistically defining what constitutes an acoustical change requiring noise testing; and
- developing equivalent procedures so that small manufacturers have alternatives to costly flight test methods.

When new or modified noise certification requirements are established for AVF aircraft, similar steps should be taken to control the complexity and cost of those procedures also.

5.3.4 FAA/ICAO Harmonization

International certification requirements need to be standardized in order to reduce noise certification costs associated with all vertical flight aircraft exported to other countries. The FAA should take the lead in establishing joint international standards to preclude the possibility of more prohibitive international standards being initiated by other countries. There are ongoing efforts to harmonize ICAO and FAA noise standards for helicopters; in the future, this effort should be expanded to include AVF aircraft. As mentioned earlier, the December 1991 CAEP meeting addressed AVF aircraft noise standards development. An FAA/ICAO task force should be formed to coordinate development of domestic and international standards.

5.3.5 Metrics

5.3.5.1 Noise Certification

Current metrics used for rotorcraft noise certification (EPNL) may be biased toward predicting the effects of high frequency noise produced by turboprop aircraft. There is some concern about the adequacy of these metrics for predicting the low frequency noise emitted from AVF aircraft accurately. Metric studies need to be conducted in advance of and during certification rule development/modification.

Existing acoustic research must be collected and evaluated for its applicability to vertical flight noise. A decision must be made on whether re-evaluation of the standard noise certification metric is warranted so that noise R&D can be conducted using consistent measurements. Such a decision will help government, industry, and academic institutions plan their future R&D requirements.

5.3.5.2 Community Acceptance

In conjuction with continued use of the DNL metric for describing long-term noise exposure, steps should be taken to improve public

understanding of that metric and the methodologies supporting it. Federal agencies generally provide a "layman's" explanation of the noise analysis methodologies used in documents describing environmental impacts of proposed Federal actions. However, many such explanations need further simplification to achieve a broader understanding of the noise impacts of proposals, actions, and alternatives. A better explanation of DNL must be developed in terms related to an average person's experience. In addition, a good explanation of why DNL is used as the overall metric for analyzing aircraft noise impacts around airports and heliports is needed to improve the public's understanding of aviation noise assessment.

To expand understanding of human response to noise, the following four tasks need to be performed:

- a lab survey of human response to AVF aircraft noise,
- a community survey with operational AVF aircraft,
- incorporation of land use planning and low noise procedures into both surveys, and
- establishment of Federal guidelines for what dB level will be acceptable at vertiports.

A means of quantifying vibration resulting from vertical flight operations may also be needed. ISIS has potential for supporting human response studies in this area.

CERL plans to develop a method for predicting the long-term average noise levels of helicopter operations in and around airfields. This research has direct application to civil heliports and vertiports. In addition to the usual incorporation of flight paths and operations counts, the proposed method will consider the effects of source height, local climate, and types of ground surfaces on average sound levels. The proposed technique will combine theory and existing experimental results from over 500 measurements of helicopter noise propagation to distances up to 2.4 kilometers, taken under a variety of conditions. This data will be used to guide development of empirical relationships that describe the dependence of measured sound levels on measured meteorological conditions. As planned, local climate and surface data (specific to a given airfield) will then be used to assign distribution percentages to the sound levels expected from empirical relationships. The end result of this research will be specifications for long-term average helicopter noise prediction. The vertical flight noise R&D community should maintain coordination with the CERL activity to assure that civil public acceptance issues are addressed in this effort.

5.3.6 Simulation Tools

5.3.6.1 HNM

The HNM must be stabilized and run bug-free for all types of helicopters. This work is ongoing by the FAA. Problems that need to be resolved include the instability of the program's Z-component functionality, ground hover, taxi operations, and transitional/ descending operations. In addition, the HNM needs to be upgraded to generate AVF aircraft noise contours. This will be necessary for 14 CFR 150 noise compatibility programs for vertiports. Since the application of 14 CFR 150 to vertiports is dependent on the availability of HNM noise contours for AVF aircraft, it is important to begin this work in the near term.

The FAA currently uses the Integrated Noise Model (INM), the HNM, and ISIS for noise compatibility planning under 14 CFR 150, but not for 14 CFR 36 noise certification. These simulation tools could have potential applications for future noise rule development for AVF aircraft.

5.3.6.2 ISIS

Ongoing FAA efforts that should be continued include upgrading and enhancement of ISIS. Currently, this model contains high quality noise recordings only for fixed-wing aircraft and only takes into account airport environments. The next planned upgrade is another 100-track digital soundtrack with more fixed-wing aircraft and some helicopters. Even with this rotorcraft functionality added, work also needs to be done to simulate the vertiport environment, so that ISIS can be used as a stand-alone model in support of vertiport noise compatibility planning.

5.3.7 Vertiport Noise Compatibility Planning

Application of the noise compatibility process outlined in 14 CFR 150 must be expanded to include vertiports. This will require acquisition of acoustic data for AVF aircraft, upgrade of the HNM to allow development of noise contours for these aircraft, and a better understanding of the environment in which vertiports will be located. This increased operational understanding must include vertiport physical data, noise abatement flight profiles, and noise impact studies of various land uses surrounding a vertiport. Siting analyses using improved tools such as GIS will be needed to predict the effects of various vertiport configurations on surrounding communities.

5.3.8 FAA/Industry Liaison

An active, cooperative partnership needs to be developed between the FAA and industry so that both are prepared to use the results of current R&D and data collection. Open lines of communication

between various interest groups in the vertical flight industry and the FAA are necessary so that progress is made safely but without unnecessary and possibly costly restrictions. A program needs to be established so that noise data and R&D issues flow effectively between the two parties. The FAA/Georgia Tech Tiltrotor Noise Workshop held in March 1991 was a positive initial step. The R&D Initiative launched in November 1992 by the FAA's Southwest Region is another effort in which industry and government will participate as team members to identify specific, potential R&D projects that practically and cost-effectively meet their mutual needs. The intent is to develop an annual program plan to prioritize and schedule proposed projects.

The FAA must lead the way with strong support for noise R&D, with modified noise regulations that will reduce test complexity and lower certification costs, and with enhanced noise models. In order for industry to be involved, they must be convinced that they will see a return on their R&D dollars. For example, noise prediction methodologies will not be developed by industry unless they can be used to lessen the costs of certification testing and/or there is a defined noise standard for AVF aircraft that necessitates accurate prediction of noise characteristics to enhance design of next generation AVF aircraft.

5.3.9 Top-Level FAA Action Committee

It may be beneficial to have a top-level action committee within the FAA to plan, enforce, and expedite noise rule development, acoustic data acquisition, computer model upgrades, etc. For example, concurrent efforts by different offices are required to develop terminal area noise abatement procedures and AVF aircraft noise certification requirements. If this is not done concurrently, the possibility of conflict is likely, i.e., AEE may develop certification requirements based on 6-degree approaches, while Flight Standards develops approach standards at 9 degrees. Coordination must be started early enough for all involved divisions of the FAA to work toward the same goals.

5.4 COMMUNITY ACCEPTANCE

R&D requirements to enhance community and public acceptance of vertical flight aircraft noise are summarized in figure 5.

5.4.1 Simulation Tools

Existing computer tools (HNM, ISIS) should be modified and new tools (GIS) developed to predict/simulate the effects of vertiport noise on the surrounding community based on operational parameters, vertiport geometry, population, and land use parameters. From such studies, the FAA should develop a land use and noise compatibility matrix specifically for vertical flight

COMMUNITY ACCEPTANCE R&D REQUIREMENTS

SIMULATION TOOLS

- Develop/modify computer tools (HNM, ISIS, GIS) to predict/ simulate effects of vertiport noise on surrounding community
- Develop a land use/noise compatibility matrix specifically for vertical flight aircraft
- Correlate computer simulation with human response studies

OPERATIONAL MEASURES

- Continue FLY NEIGHBORLY program
- Test feasibility of using position recording/tracking system for control of noise abatement operations
- Develop helicopter route structures for metropolitan areas
- Develop noise abatement procedures for terminal areas

COMMUNITY EDUCATION

- Develop community acceptance primers, videos
- Form national FAA/industry committee to disseminate vertical flight information to communities
- Present ISIS demonstrations to public groups

VERTIPORT NOISE COMPATIBILITY PLANNING

- Apply 14 CFR 150 process to vertiports to conduct noise compatibility planning
- Develop system planning guidelines for vertiports, documented by case studies
- Complete inventory of regulatory and advisory noise and land use controls (local, metropolitan, and state)
- Establish a level of tiltrotor noise reduction required for acceptable operation at selected classes of vertiports
- Undertake further market analysis to evaluate tiltrotor use at these selected classes of vertiports subject to realistic commercial acoustic and performance constraints

FIGURE 5 COMMUNITY ACCEPTANCE R&D REQUIREMENTS

aircraft. Human response studies need to be conducted and correlated with these computer simulations.

5.4.2 Operational Measures

The HAI's Fly Neighborly Program begun in 1981 should continue its objective of promoting and practicing voluntary noise abatement operations to provide maximum environmental benefits to the community. Crew member awareness/training should be expanded to inform vertical flight operators about noise abatement piloting techniques and to educate them about the importance of being a "good neighbor." This can be done by incorporating the fly neighborly philosophy into training materials, flight manuals, and aircraft handbooks. The scope of the pilot training program should also include:

- initial and recurrent flight training for pilots,
- incorporation of noise data into flight manuals,
- preparing and distributing specific vertical flight aircraft noise data,
- preparing and distributing recommended noise abatement procedures,
- organizing and holding operator and manufacturer seminars, and
- providing environmental and supervisory personnel training courses.

These guidelines are discussed in detail in the Fly Neighborly Guide published by the Fly Neighborly Committee of HAI (reference 15).

HHOA has plans to develop an even more controlled program than the one currently in operation, described in section 4.4.3. Using helicopters equipped with global positioning system (GPS) receivers and flight-following capability, HHOA plans to test a position recording/tracking system for even tighter control of noise/nuisance abatement operations. A test program, supported by the FAA, is planned for 1993. This program will be conducted on the island of Hawaii because many of the complaints have come from tourist flights around the volcanoes and lava flow areas. Five aircraft, from different operators, will be equipped with a Garmin AVP-100 GPS receiver and a Bi-tronics microprocessor unit. These aircraft will conduct flights over specified points, chosen by the HHOA and the FAA's Hawaii Flight Standards District Office, that are commonly traversed during daily operations. FAA officials will survey these points with a hand-held GPS receiver and an altimeter. Each point will be overflown at 500, 1,500, and 3,000 feet above ground level while recording latitude, longitude, altitude, and time. This information will be transmitted on ultra-high frequency (UHF) via a digipeater to a base station at the Hilo Airport. This portion of the test will be used to verify the accuracy of the system. When accuracy

tests are completed, the system will be used in daily operations to assess its reliability and maintainability. Other issues that will be addressed during this period are frequency of position transmission from aircraft to the base station and permanent installation requirements.

A test plan will be submitted by mid-June and a report on the results of the test will be submitted 6 months after commencing the program. If the test results are favorable, this system may be expanded to cover all of the Hawaiian Islands.

Low altitude IFR and VFR helicopter route structures should be developed for all high density rotorcraft traffic areas in metropolitan regions. These route structures should connect with standard instrument departure routes and standard terminal arrival routes that incorporate noise abatement procedures developed for AVF aircraft. The principles of flight trajectory management, as well as variations in routings and flight profiles, will be used in development of these procedures.

5.4.3 Community Education

The FAA and industry should develop community acceptance primers that address vertical flight technology and resulting noise as part of an intermodal transportation system that could greatly benefit the community. These primers need to address different, but interested audiences, including:

- professional city planners,
- planning commissions,
- city managers/administrators,
- public organizations, and
- the public/community-at-large.

In addition, an FAA/industry committee should be established to disseminate vertical flight information to communities. The use of community education tools such as ISIS, that could actually let public groups "hear" a tiltrotor at selected locations and under varying conditions, and videos that discuss vertiports and their benefits to an urban area could be part of such an effort. However, ISIS must be applied correctly and used in a strictly controlled manner to prevent misrepresentation of vertical flight noise by opponents of such aircraft.

5.4.4 Vertiport Noise Compatibility Planning

Application of the noise compatibility process set forth in 14 CFR 150 should be expanded to include not only heliports, but also vertiports where AVF aircraft will conduct operations. To enable this process to be used for vertiports, the HNM must be upgraded to include AVF aircraft noise data so that accurate noise exposure maps may be prepared that identify present and

future noise levels and the surrounding land uses which are not compatible with those noise levels. The second part of the 150 process, developing a Noise Compatibility Program, will further enhance community acceptance of vertiports. Such a document will provide a vehicle for guiding and coordinating all agencies and individuals whose combined efforts are essential to achieve the maximum degree of noise compatibility between the vertiport and its neighbors, while also taking into account the requirements of the NAS.

The FAA should document, through case studies, successful and unsuccessful proposed vertiport projects to define and determine a systems planning approach. In addition, a study of proper land use planning for vertiports needs to be conducted, to include a complete inventory of regulatory and advisory noise and land use controls (local, metropolitan, and state).

Guidelines need to be developed that clearly define issues and mitigating methodologies for urban/transportation planners to evaluate community acceptance of vertical flight noise. As data from AVF aircraft noise studies becomes available, they should be included in the guidelines. Noise elements need to be explicitly defined, along with their effects on different types of heliport/vertiport environments. For instance, a specific noise level will have more impact on residential land use than on commercial or industrial areas. Guidelines will enable planners to weigh the category of heliport/vertiport (public use, commercial service, private use, hospital, etc.) and the intensity of operations (number of operations, mix of rotorcraft types, multiple approach and departure paths) to predict community acceptance. Additional considerations may include the level of ambient noise within the existing/proposed environment and the value of the heliport/vertiport to the economic well-being and safety (e.g., emergency preparedness) of the community.

A level of tiltrotor noise reduction required for acceptable operation at selected classes of vertiports should be established. Further market analysis should be undertaken to evaluate tiltrotor use at these selected classes of vertiports subject to realistic commercial acoustic and performance constraints.

6.0 LONG-RANGE REQUIREMENTS

For purposes of this plan, long-range requirements are defined as efforts planned for execution in the longer term, i.e., the 1997 to 2002 timeframe. Most of these requirements are largely extensions and/or expansions of efforts that will be initiated as near-term projects. Depending on research results and data acquired, they may need to be re-evaluated at a later time for continued relevance or validity.

Due to the uncertainties inherent in trying to predict requirements in the distant future, this section is far less specific than the descriptions provided for near-term requirements. However, as the program evolves over time, this plan will be updated to "fill in the blanks" as required.

6.1 TECHNICAL

Long-range technical requirements are described below.

1. Additional flight data on tiltrotor noise is needed to verify scaling from model-scale data to full-scale data. Low-noise descent can be checked only in flight. Further V-22 flight tests are needed.

2. More extensive analytical evaluations of the impact of blade designs, number of blades, and multi-bladed hubs on tiltrotor aircraft noise are needed. These models should be adequately verified against wind tunnel test data.

3. Extensive wind tunnel tests should be carried out to study the effects of blade designs, number of blades, and multi-bladed hubs on tiltrotor aircraft noise.

4. A prediction code that would allow noise prediction for any size tiltrotor is needed.

6.2 OPERATIONAL

Long-range operational requirements are described below.

1. Operational guidelines are needed for reducing noise on takeoff and landing, and for layout of glideslope corridors for minimal noise. CERL plans to fund a project, Flight Operations for Noise Minimization, to test various strategies for reducing noise levels on landing and takeoff, and in glideslope and flight corridors. At present, there are no guidelines for helicopter landings, hovering, or takeoffs to reduce noise impact on specially designated locations. From previous tests with vertical flight aircraft, it has been established that many factors influence the sound output of a single craft or single class

of aircraft. The flight path chosen, rate of descent/ascent, rotor speed, and maintenance record all seem to play a role. A change in pilots also may contribute to different noise levels because of differing flight practices or habits. The FAA should coordinate with CERL on this effort in order to benefit from the findings of this project.

6.3 REGULATORY

Long-range regulatory requirements are described below.

1. The FAA must continue to develop a comprehensive noise database, formatted in a standard noise metric, that can be used as an internal FAA tool for noise reference. This database would also be available to industry, especially small and derivative design manufacturers, for obtaining noise data and possibly for certification of derivative designs using computer analysis.

2. When AVF aircraft noise data becomes available, metric study should be continued and an evaluation made of the adequacy of current certification metrics for representing that noise.

3. The results of ongoing R&D in noise reduction must be applied to AVF aircraft noise certification requirements in order to keep them up-to-date. New noise abatement procedures or metrics to predict public response to AVF aircraft noise should be developed to allow more accurate predictions of noise impacts and public reaction to this noise.

6.4 COMMUNITY ACCEPTANCE

Long-range requirements to promote community acceptance are described below.

1. Simulation tools such as the HNM and ISIS should continue to be upgraded to incorporate improved noise recordings and/or recordings of new aircraft types, including AVF aircraft. As technology for predicting acoustic performance advances, these models will become increasingly sophisticated and realistic.

2. Efforts should continue to promote community education and acceptance of the potential benefits that vertical flight aircraft can contribute to the NAS, as well as to individual communities.

3. A model should be developed for predicting individual response to noise. CERL plans to conduct a project to assess current procedures that deal with average communities

and average people. This work will explain and quantify the variation from individual to individual and from community to community. Both acoustical and non-acoustical factors will be considered. At the individual level, this effort should help clarify the relationship between noise complaints and individual noise annoyance, a relationship that is totally lacking when dealing only with average communities. The FAA should coordinate with CERL on this effort in order to benefit from the findings of this project.

7.0 MILESTONE SCHEDULES

This section contains specific milestones that need to be met in order to satisfy the requirements detailed in sections 5.0 and 6.0. At the present time, insufficient data on schedules is available to accurately complete this section. Many of the external events that will drive the milestones in the vertical flight noise R&D program have ambiguous dates at this point.

As a means of structuring the numerous requirements in this plan, figure 6 depicts a preliminary flow diagram of integrated milestones that support the goals and objectives of the four major areas of the vertical flight noise R&D program. The column labeled "helicopters" represents tasks or projects that may be initiated at the present time. Those tasks under "prototype AVF aircraft" are requirements to be undertaken in the near future when those aircraft are available. Milestones in the third column are longer term requirements that will coincide with the development of first generation AVF aircraft.

A limited number of specific milestones currently planned by various organizations involved in vertical flight noise R&D are included below. In addition, it is anticipated that the FAA will sponsor a workshop at a later date to allow experts in each of the areas covered in this plan to review the information provided and offer comments/ additional data in order to make the plan as accurate and complete as possible.

7.1 FEDERAL AVIATION ADMINISTRATION

Milestones currently planned by AEE include the following:

- completion of studies on community response to aviation noise and development of techniques to promote cooperative community participation in aviation planning (FY 93/94);
- noise flight tests of heavy helicopters, tiltrotors, and advanced transport aircraft (FY 93/94);
- evaluation of ISIS and its future development/ utilization (FY 93/94);
- upgrade of HNM (FY 94/95); and
- a joint program with NASA to develop new noise reduction technologies and noise abatement operating procedures (FY 93/99).

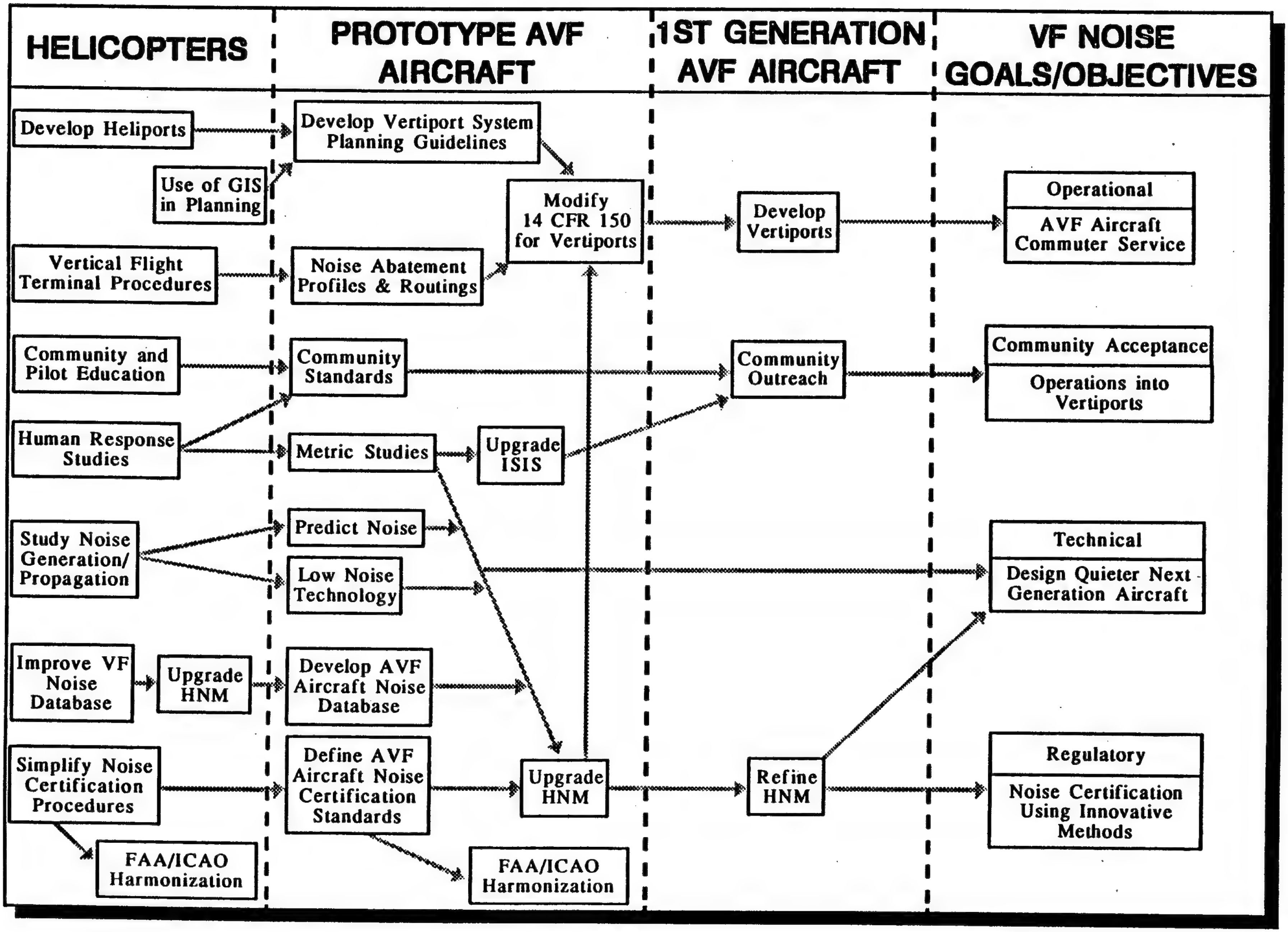


FIGURE 6 VERTICAL FLIGHT NOISE INTEGRATED MILESTONES

Milestones currently planned by the VFPO include the following:

- development of environmentally acceptable VFIPS for the terminal area (VERTAPS program) (FY 98); and

- development of environmentally acceptable vertical flight ATC procedures for the terminal area (VERTAPS program) (FY 98).

7.2 NASA

As discussed throughout this plan, NASA is currently formulating plans for its AT^3 Program. The key objective of this research program is to develop validated technology for safe, quiet, economically competitive CTR operations. Program goals include reducing community noise near vertiports, and reducing interior noise and improving ride comfort to enhance passenger acceptance. Personnel from Langley, Ames, and Lewis Research Centers have formulated a tentative plan to be submitted to OAET (date TBD). The revised final version is expected to be approved in 1993, submitted to the Office of Management and Budget (OMB), and submitted to the Congress in January 1994. The draft AT^3 milestone chart prepared by NASA is included here as figure 7.

7.3 U.S. ARMY

Milestones currently planned by CERL include the following:

- DOD noise source human response characterization (general impulse response model) (FY 94);

- development of an international method for long-term helicopter noise prediction (NATO standard for helicopter noise propagation) (FY 94);

- noise assessment procedures and management systems (FY 95);

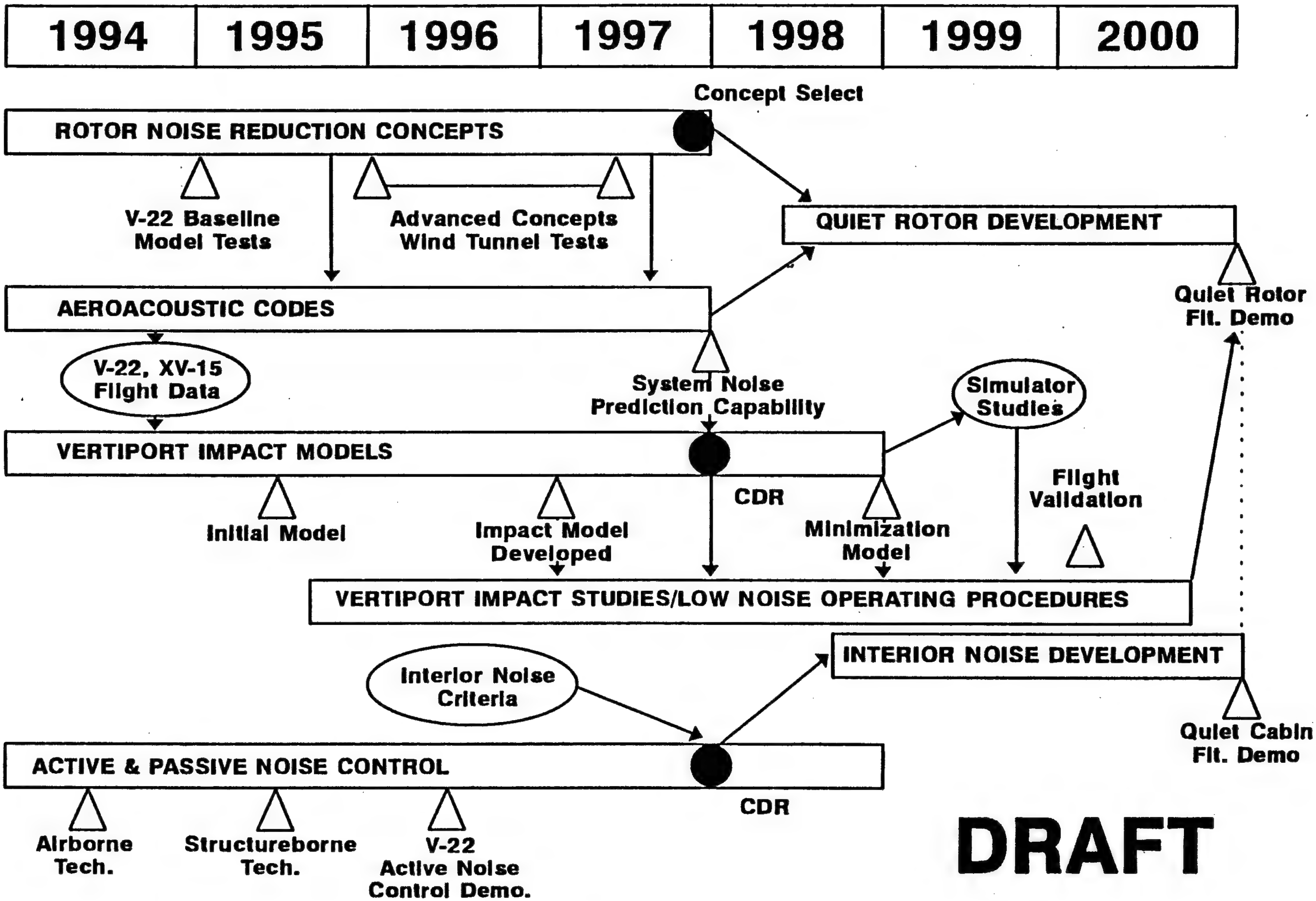
- active noise cancellation for limited area sources (FY 96);

- flight operations for noise minimization (helicopter aircraft noise minimization) (FY 97); and

- analyses of individual human responses to impulsive sound (FY 99).

7.4 VERTICAL FLIGHT AIRCRAFT MANUFACTURERS - TBD

7.5 ACADEMIA - TBD



Source: NASA Advanced Tiltrotor Transport Technology Program Plan

FIGURE 7 AT^3 NOISE REDUCTION MILESTONE SCHEDULE

8.0 RESOURCE REQUIREMENTS

This section will contain resource requirements necessary to accomplish the efforts detailed in sections 5.0, 6.0, and 7.0. However, at the present time, insufficient data is available to accurately complete this section.

It is anticipated that the FAA will sponsor a workshop at a later date to allow experts in each of the areas covered in this plan to review the information provided and offer comments/additional data in order to make the plan as accurate and complete as possible.

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14. "Fly Neighborly Program Manual," First Edition, produced by the Hawaii Helicopter Operators Association, 1992.

15. "Fly Neighborly Guide," produced by the Fly Neighborly Committee of the Helicopter Association International, February 1991.

LIST OF ACRONYMS

3-D	Three Dimensional
AEE	Office of Environment and Energy
AFDD	U.S. Army Aeroflightdynamics Directorate
AGC	Office of the Chief Counsel
AHS	American Helicopter Society
AIA	Office of International Aviation
APA	Office of Public Affairs
APP	Office of Airport Planning and Programming
ASNA	Aviation Safety and Noise Abatement
AT^3	Advanced Tiltrotor Transport Technology
ATB	Advanced Technology Blades
ATC	Air Traffic Control
AVF	Advanced Vertical Flight
AVSCOM	Aviation Systems Command
BERP	British Experiment Rotor Program
BHTI	Bell Helicopter Textron, Inc.
BVI	Blade Vortex Interaction
CAD/CAM	Computer-Aided Design and Manufacturing
CAEP	Committee on Aviation Environmental Protection
CASA	Construcciones Aeronauticas SA
CERL	U.S. Army Corps of Engineers Construction Engineering Research Laboratory
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CPU	Central Processing Unit
CTR	Civil Tiltrotor
dB	Decibel
DNL	Day-Night Sound Level
DNW	Duits-Nederlandse Wind Tunnel
DOD	Department of Defense
DOT	Department of Transportation
EC	European Community
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EPNL	Effective Perceived Noise Level
EUROFAR	European Future Advanced Rotorcraft
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FICON	Federal Interagency Committee on Noise
FONSI	Finding of No Significant Impact
FY	Fiscal Year
GIS	Geographical Information Systems
GPS	Global Positioning System
HAI	Helicopter Association International
HHC	Higher Harmonic Control
HHOA	Hawaii Helicopter Operators Association
HNM	Heliport Noise Model
Hz	Hertz
IBC	Individual Blade Control
ICAO	International Civil Aviation Organization

ICCAIA	International Coordinating Council of Aerospace Industries Association
IFR	Instrument Flight Rules
INM	Integrated Noise Model
ISIS	Interactive Sound Information System
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Systems Command
NCP	Noise Compatibility Program
NEM	Noise Exposure Map
NEPA	National Environmental Policy Act of 1969
OAET	Office of Aeronautics Exploration and Technology
OMB	Office of Management and Budget
R&D	Research and Development
RMP	Rotorcraft Master Plan
RPM	Revolutions per Minute
SEL	Sound Exposure Level
STC	Supplemental Type Certificate
STOL	Short Takeoff and Landing
TERPS	Terminal Instrument Procedures
TIGER	Topologically Integrated Geographic Encoding and Referencing
TRAM	Tiltrotor Aeroacoustics Model
UHF	Ultra-high Frequency
VERTAPS	Vertical Flight IFR Terminal Area Procedures
VFIPS	Vertical Flight Instrument Procedures
VFPO	Vertical Flight Program Office
VFR	Visual Flight Rules